THE DEVELOPMENT OF TASMANIAN SHORE PLATFORMS

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I hereby certify that this thesis is all my own work and that no part thereof has been previously used by me for any other diploma or degree.

M. W. Sanders

"Look beneath the surface; let not the several quality of a thing nor its worth escape thee."

Marcus Aurelius, Meditations vi, 3

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THE PROBLEM

Horizontal shore platforms at the approximate level of high tide have been recognized as features of the world's coastlines for over 100 years. Since the mid 19th Century, geologists and geomorphologists have described these platforms and attempted to account for their origins. Interest has continued in shore platforms for two reasons: platforms are notable in themselves as coastal features and they have been used to indicate past sea levels.

The great deal of disagreement in the literature over the processes of formation indicates the lack of actual knowledge about developmental details. Recent studies have concentrated on determining the details of platform formation, but many processes still need clarification. Until these details are known, there is little point in citing characteristic elevations of horizontal, high tidal shore platforms as evidence of sea level change.

Earlier workers tended to neglect three major avenues of investigation which are important in defining the processes involved in shore platform development. The three approaches are precise mapping of the platform surfaces, laboratory work including wave tank experiments, and underwater study. In addition, the influence of biological factors, climate, wave characteristics and tidal regime were often overlooked. This thesis is an attempt to explain the development of Tasmanian shore platforms using precise measurement, experimentation and underwater investigation, combined with recognition of the influence of organic and environmental considerations. Information gained will be combined with knowledge set forth by previous workers to determine the factors involved in Tasmanian shore platform development.

Although the present study is primarily concerned with the development of horizontal, high tidal platforms, all the basic Tasmanian platform types are considered. Determination of processes is facilitated by analysis of the factors leading to the production of platforms with differing slopes, surface roughness and altitudinal locations.

TASMANIA AS A LOCATION FOR SHORE PLATFORM STUDY

The island state of Tasmania supports a wide variety of rock shore platforms in or near the intertidal zone (Figure 1). The numerous, diverse platforms and the relative tectonic stability of the island combine to favor the study of shore platform development. Evaluation of the effect of rock type

Figure 1

SIGNIFICANT TASMANIAN BEDROCK SHORE PLATFORMS

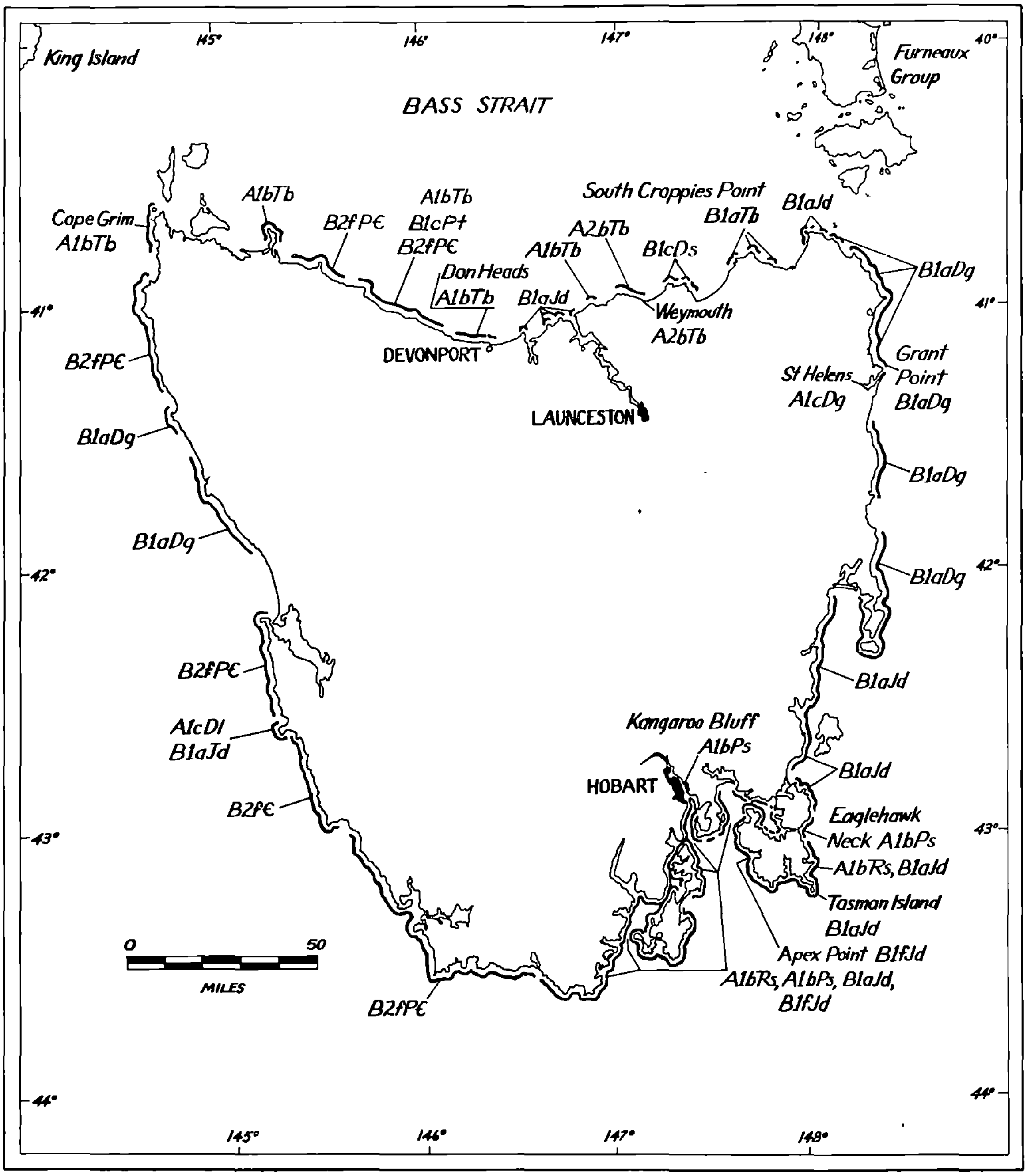
The heavy black line along the coast signifies that the platform type indicated frequently occurs in the included area. The line does not imply that all rocks in the area show identical development or that the entire coast is composed of platforms. Large sections of coast not fronted by heavy black lines are predominantly beaches. Names, such as "Cape Grim" and "Apex Point" on the map show the location of platforms which receive detailed description in Section II.

Key to the platform types is on page xxii of the Introduction.

Geological key follows:

Tb	-	Tertiary Basalt
Jd	-	Jurassic Dolerite
₸s	-	Triassic Sandstone
Ps	-	Permian Siltstone and Sandstone
Pt	-	Permian Tillite
Dg	-	Devonian Granite
Dl	-	Devonian Limestone
Ds	-	Devonian Siltstone and Sandstone
Є	-	Cambrian Sediments
PЄ	-	Precambrian Sediments (Metamorphosed)

Based on the map "Geology of Tasmania" (1; 506,880) Dept. of Mines, Hobart, 1961



King Island
145°
146°
147°
148°
40°
Furneaux Group
BASS STRAIT
A1bTb
A1bTb
B1cPt
B2fPЄ
B2fPЄ
South Croppies Point
B1aTb
B1aJd
Cape Grim
A1bTb
A2bTb
A1bTb
B1cDs
B1aDg
Don Heads
A1bTb
B1aJd
41°
Weymouth
A2bTb
DEVONPORT
Grant Point
B1aDg
B2fPЄ
St Helens
A1cDg
LAUNCESTON
B1aDg
B1aDg
B1aDg
42°
B1aDg
B1aJd
B2fPЄ
Kangaroo Bluff
A1bPs
A1cDl
B1aJd
B1aJd
HOBART
B2fЄ
Eaglehawk
Neck A1bPs
43°
A1bRs, B1aJd
Tasman Island
B1aJd
0
50
MILES
Apex Point B1fJd
A1bRs, A1bPs, B1aJd,
B1fJd
B2fPЄ
44°

on shore platform formation is made possible by the occurrence of such different lithologic types as dolerite, granite, quartzite and a number of sedimentary rocks in coastal areas. The amount of wave energy striking various parts of the Tasmanian coast varies considerably allowing further comparisons to be made.

Tasmanian geologists are of the opinion that little vertical movement has taken place on the island in recent times. Tasmania, located just south of the stable mass of the Australian continent, is outside the active orogenic zones of the Pacific. Parts of Tasmania were glaciated during the Pleistocene, but the consensus is that the ice cover was too limited to prompt isostatic readjustment upon melting.

TERMINOLOGY

Shore platform literature abounds with conflicting and misleading terminology. One of the main reasons for this unfavorable situation is the tendency for workers to define shore platforms in terms of supposed developmental processes rather than on a purely descriptive basis. Genetically based terminology was widely used by the pioneer researchers, such as Gilbert (1884) who coined the name "wave cut terrace" to describe a type of sloping shore platform. The "wave cut terrace" became a widely accepted term which is still often found in textbooks.

Students of shore platforms have attempted to reform the terminology in two different ways. Some, like Bartrum (1916) and Wright (1967) proposed type location names for what they considered to be characteristic platforms (Old Hat platform, Isle of Thanet platform). This system is better than a genetic classification, but is difficult to apply if the Old Hat and the Isle of Thanet are not personally known. In addition, the wide variation in platform morphologies would necessitate a long string of place names to accommodate all the features.

Other workers such as Johnson (1933), Jutson (1939, 1950) and Bird (1964) produced descriptive definitions or classification systems. Jutson's system, although based on description, had strong genetic overtones with major platforms, minor platforms, primary and secondary platforms, and ultimate platforms. Bird refined this system into high tide, low tide and intertidal platforms, a great improvement based on altitudinal location.

D. W. Johnson recognized the larger problem in terminology in offering a definition for shore platforms themselves. He defined a shore platform as "(A bench) lying close to the present shore, ranging from 1 or 2 feet to 5 or 6 feet above ordinary high tides, showing fresh rock surfaces usually free from debris." This definition is clear and descriptive, but unfortunately requires the re-naming of a number of features which are normally called shore platforms.

The same problem occurred in the present study. The Dictionary of Geological Terms (1962) definition for a shore platform is "Plane of marine abrasion; wave-cut terrace." A more realistic, concise definition for a shore platform is required, but the term already has so many connotations that any new definition is severely restricted by present usage. Working with the Webster's New Collegiate Dictionary (1949) definition of a platform as "A horizontal, generally flat and raised surface", the British Isles would be almost innocent of shore platforms. In addition, a sloping shore platform would be a terminological solecism.

Bowing to the limitations imposed by usage, shore platforms in this study refer to horizontal or sub-horizontal coastal rock surfaces in or near the intertidal zone. However, the problem of defining individual shore platform types still remains. As a step towards clarification of terminology, the following classification system was produced after examination of a number of Tasmanian platforms. The system is based on the amount of horizontality present on a platform surface, smoothness of the surface and altitudinal location. Letters and numbers preceding the designations are keys for the accompanying map of Tasmanian Shore Platforms (Figure 1).

SHORE PLATFORM DEFINITIONS

Horizontality

A. Horizontal shore platform:- Bedrock surface of at least 1000 $ft.^2$ area, having a mean slope of from 0^o to not more than 3^o. Surface slope deviations from the mean slope must be less than $\pm 1^o$, measured over any 10 foot distance.

B. Sloping shore platform:- Bedrock surface of at least 1000 $ft.^2$ area, having a mean slope of greater than 3^o.

Surface Characteristics

1. Smooth surface: Total relief variation of from 0" to not more than 6" in any square $10ft.^2$ portion of the entire $1000ft.^2$ area. Variation to be measured from the mean slope plane.

2. Rough surface: Total relief variation of more than 6" in any square $10ft.^2$ portion of the entire $1000ft.^2$ area. Variation to be measured from the mean slope plane.

Altitudinal Location

a. Supratidal: Higher than one foot above the level of mean higher high water.

b. High Tidal: Within one foot above or below the level of mean higher high water.

c.	Intertidal	From one foot below the level of mean higher high water to one foot above the level of mean lower low water.
d.	Low Tidal	Within one foot above or below the level of mean lower low water.
e.	Subtidal	Lower than one foot below the level of mean lower low water.
f.	Transgressive	Extends continuously from supratidal to subtidal zones.

ORGANIZATION OF THESIS

The study is divided into three main parts. Section I follows the development of ideas pertaining to shore platforms from 1849 to the present. Section II describes a number of significant Tasmanian shore platforms in detail as a foundation for Section III. The final section combines previous theories with information gained from field study and experiments to isolate the factors important in the development of Tasmanian shore platforms. Chapter 17, describing the formation of the Tessellated Pavement, presents an example of how the factors discussed in Section III interact in producing an actual platform. Following Section III are two appendices: "Construction of a Simple, Portable Tide Gauge" and "Stereo Photography from Light Aircraft".

SECTION I

EVOLUTION OF SHORE PLATFORM THEORY

INTRODUCTION

Shore platforms first received scientific attention in the mid-nineteenth century. Unfortunately, progress in shore platform study has been painfully slow since that initial recognition and many more recently isolated aspects of coastal geomorphology show much more comprehensive development. Early workers in the field concentrated on descriptions of shore platforms and broad outlines of processes active in their formation. Today, the emphasis is on proving, disproving or elaborating upon the many theories advanced concerning shore platform production.

A diversity of views characterizes shore platform literature, which also reveals definite geographic groupings of studies. The variations in opinions seem to be a function of the distribution of observations. Early workers in the shore platform field tended to be dogmatic about their favorite formational theories which often were applicable in only the narrow range of conditions prevailing in a specific area.

The study of shore platforms has not been conducive to the development of specialists in the one field. Many geologists and geomorphologists have been involved in the subject but usually only in passing. The most prolific contributor to the literature, the New Zealander J. A. Bartrum, (eight articles between 1916 and 1952) was a hard-rock geologist who studied shore platforms only periodically.

Selection of Material.

Articles were arbitrarily included or excluded in this discussion on the basis of how much it was felt that they contributed to the development of knowledge about shore platforms. The papers which were chosen may be devoted entirely to the subject or have degrees of involvement ranging down to a few sentences. Articles concerning coral reef forms and solutional features in limestone were not considered unless they contained information applicable to the development of shore platforms in non-calcareous rocks. Because of the subjective screening, the number of articles in this review is not a good indication of the total output of literature mentioning shore platforms. As a rough estimate, the publications treated may comprise about half of the world total on the subject.

Temporal Distribution of Publications.

Although the number of papers in this review is not an exact indicator, relative trends in publication are apparent. As might be expected, the frequency of publication increases as the present is approached. Even so, as recent a year as 1962 showed no articles in the field. The sudden increase in publications during the period just before World War II is accounted for, at least in part, by the impetus given by the printing of the Journal of Geomorphology under the guidance of D. W. Johnson.

The Journal devoted much editorial effort to the subject of shore platforms and this field in particular suffered when publication ceased during World War II. The years from 1958 to 1961 were productive, with publications in the later year being the most numerous on record. The large number was a result of articles mentioning shore platforms in the Zeitschrift volume devoted to sea level change. Even in this most prolific year, the total number of articles was only five.

Geographic Distribution of Publications.

Although shore platforms enjoy world-wide distribution, two-thirds of the publications were concerned with features in and around the Pacific Ocean. Of these, by far the greatest number, (sixteen), were located in Australia, with eleven in New Zealand, four in Hawaii and the rest scattered from Japan, through the Aleutians to the coast of California.

A. B. Edwards, E. S. Hills and J. T. Jutson, called the "Melbourne School" by Guilcher, (1958), accounted for the bulk of the Australian literature. These writers produced fifteen articles which contained major mention of shore platforms. J. T. Jutson (1950) devoted one entire paper to the subject of classification and terminology of shore platforms and, along with the other two authors contributed greatly to knowledge of the field.

Organization of Section.

The discussion of the evolution of shore platform theory is divided into two chapters. Chapter I includes the period of description, from 1849 to 1938, and Chapter 2 covers the period of measurement, from 1938 to the present. Like all artificial divisions, the classification is not strictly accurate. Some measurement was done before 1938 and a great deal of descriptive material has been written since that date, but the emphasis has definitely shifted. J. D. Dana's 1849 work initiated the descriptive period and the 1938 paper presented by C. K. Wentworth marked the beginning of the period of measurement.

Chapter 1

THE PERIOD OF DESCRIPTION - 1849-1938

THE PIONEERS - 1849 to 1890

J. D. Dana - Describes Shore Platforms, Recognizes Importance of Weathering and Wave Action.

James D. Dana, geologist of the U.S. Exploring Expedition of 1838 to 1842, apparently was the first worker to publish a detailed description of shore platforms (1849). Dana's discussion of the platforms of New Zealand and Australia foreshadowed the dominance of these areas in the literature which continues to the present. Captain James Cook, who explored the same regions in the previous century, made no mention of shore platforms, although a drawing he produced in the Bay of Islands, New Zealand, in December, 1769, shows the characteristic "Old Hat" type of formation in the background. Darwin, during the "Beagle" voyage of 1831 to 1836, visited the Hobart, Tasmania area and parts of New South Wales, but failed to mention shore platforms. This omission is in spite of the probability that Darwin walked on the features during his discovery of elevated deposits of marine sediments and shells along the Derwent River and Storm Bay in Tasmania.

J. D. Dana in his study of the shore platforms of New South Wales and New Zealand described occurrences of both the structurally controlled and "Old Hat" type. The actual "Old Hat Island" of

Russell, New Zealand, so impressed him that he included a sketch of it in his "Manual of Geology" (1880). Dana gave great importance to saturation as a control over depth of sub-aerial weathering, but still favored hydraulic hammering and abrasion by rocks and sand as the chief agent in platform cutting. He theorized that the actual height of the platform surface was related to the "level of greatest wear" which is a function primarily of wave height with secondary control exerted by tidal interval.

Dana, in his "New Textbook of Geology", (1883), p.107, 108, restated his earlier views with little change in a section headed: "Waves, Level of Greatest Eroding Action." Dana said "The eroding action is greatest for a short distance above the height of half-tide and, except in violent storms, it is almost null below low-tide level. Fig. 110 represents in profile a cliff, having its lower layers, near the level of low tide, extending out as a platform a hundred yards wide. As the tide commences to move in, the waters, while still quiet, swell over and cover this platform, and so give it their protection; and the force of wave-action, which is greatest above half tide, is mainly expended near the base of the cliff, just above the level of the platform. But for much battering effect a coast should be shelving, so as to raise the waters as they advance. If deep alongside of a cliff, there is simply a rise and fall, with little abrasion." This concept of "level of greatest wear" would seem at first to be the ancestor of the present day storm wave formation theory, but closer examination shows that Dana implied that erosion would take place below low-tide level during violent storms.

Dana's views on weathering appear to have formed the foundation for J. A. Bartrum's explanation of the platforms found on "Old Hat" Island in New Zealand. Bartrum (1916) ascribed the platforms to inhibition of sub-aerial weathering by a level of saturation, with removal of eroded material by wave action. Dana mentioned this possibility, but emphasized wave erosion as the chief formative factor. Dana, like many advocates of "storm wave erosion" who were to follow, never fully explained why there should be a level of greatest wear a short distance above high tide.

Even though lacking in detail, Dana's ideas were very astute and in the light of present knowledge can be seen to be correct in certain locations where bedding is horizontal, beds are differentially resistant, and wave energy is high. His principal error was in failing to recognize the potency of weathering, which is very often more instrumental in platform production than straight hydraulic action. However, because workers over 100 years later were still proposing wave action as the chief cause of shore platforms, Dana should not be too greatly criticized. His perception was remarkably keen, and if he had concentrated on the problem of shore platform development, there might be little to add today.

<u>G. K. Gilbert - Describes Wave Cut and Wave Built Terraces; Outlines Processes.</u>

In 1884, G. K. Gilbert of the United States Geological Survey published a very important piece of geomorphological literature pertaining to lake shores. Gilbert included a specially arranged chapter of his then incomplete monograph on Lake Bonneville, Utah, in the Fifth Annual Report of the U.S.G.S. He spent considerable time studying the exposed shore features of ancient Lake Bonneville before producing a 48-page article entitled "The Topographic Features of Lake Shores." Gilbert dealt with spits, bars, hooks and other depositional features, in addition to erosion forms. Shore platforms and "wave built terraces" were treated at some length.

Gilbert wrote that wind waves and, less importantly swell, wear away the shoreline by abrasion using tool stones. These stones are moved forcefully about by breakers until they are worn to a small size and carried away by undertow. He differs with Dana in stating that, while simple impact of large masses of water may carry away unconsolidated material, hydraulic action has little or no effect on solid rock. In support of this view, Gilbert cited deposits of calcareous tufa on the shores of Lake Bonneville which were exposed to vigorous wave attack. His other views seem to parallel Dana's "Level of greatest wear", however, as Gilbert stated: "The direct work of wave erosion is restricted to a horizontal zone dependent on the height of the waves. There is no impact of breakers at levels lower than the troughs of the waves; and the most efficient impact is limited upward by the level of the wave crests, although the dashing of the water produces feebler blows at higher levels." He added that undertow and wave motion on the bottom, together with direct wave abrasion in the breaker zone, act to form a normal profile of the submerged terrace which maintains itself in equilibrium by being less subject to wave erosion in deep water than in shallow. This statement appears to be a basis for Fenneman's later (1902) article, but Fenneman does not mention Gilbert in his footnotes.

Gilbert described how wave activated erosion makes a "saw cut" in a cliff, allowing the unsupported upper portion to fall as detritus. His "wave cut terrace" was defined as "The submerged plateau whose area records the landward progress of littoral erosion." Prime characteristics are that it is associated with a cliff, that its upper margin where it joins the cliff is horizontal, and that its surface has a gentle inclination away from the cliff. This inclination depends on the nature of the material and the original slope of the land. It is greater where the material is loose rather than coherent and also greater where the ratio of terrace width to cliff height is small. The width of the terrace depends on the extent of littoral erosion which, in turn, depends on numerous factors.

A wave built terrace, Gilbert continued, may be formed from the detritus derived from cliff erosion carried along in longshore currents and ultimately forced offshore by a stream of water remaining at the surface but assuming a greater cross section and a diminished velocity. The formation of wave built terraces is most favored at the heads of triangular bays, where waves can roll in unhindered. The wind sweeping up such a bay carries the surface of the water before it and the only return is by undertow at the head of the bay. Gilbert concluded, "If the head of the bay is acute, the first embankment built is a curved bar tangent to the sides and concave toward the open water." On page 40 of the complete 1890 Lake Bonneville monograph appears a drawing which combines the wave cut bench and the wave built terrace into the grandfather of that ubiquitous section portraying coastal erosion and deposition, complete except for the convexity of wave-built slope which would be added later by Fenneman.

These papers, by Dana and Gilbert, illustrate the basic views that still prevail about what constitutes a "profile of equilibrium." Dana described a stepped form with horizontal shore platforms and steep cliffs, while Gilbert spoke of a wave cut terrace, caused by rock abrasion, which graded into a wave built feature. If the shores of Lake Bonneville were composed of horizontally bedded sandstone instead of tuff, rhyolite and alluvium, Gilbert's profile would have looked more like Dana's and the stepped profile would have been accepted more quickly. This situation points up the importance of evaluating the rock type and environmental factors before generalizing broadly on processes through the study of only one field location. Stepped profiles, graded profiles and combinations of the two can occur. Dogmatic adherence to one profile or another because of its presence in a local field area has caused considerable confusion in the shore platform literature through the years.

THE PROFILE OF EQUILIBRIUM - 1902 to 1919

N. M. Fenneman - Proposes the Profile of Equilibrium.

N. M. Fenneman, of the University of Chicago, published a major contribution to the shore process literature in 1902. The paper was entitled "Development of the profile of equilibrium of the subaqueous shore terrace" and its importance lay in the establishment of the concept of equilibrium and its relationship to erosive and transportational activities extending to wave base. Fenneman wrote that adjustments of the shore to current, slope and load, once attained, may be maintained fairly constantly in a "profile of equilibrium." Fenneman considered that when this profile was once reached, it might shift position towards or away from the land, but the slope would remain constant.

Waves, generated by wind, were proposed as the source of the energy needed for development of the profile of equilibrium. Fenneman listed three agencies which shaped the bottom: (1) oscillatory wave action and undertow, carrying material seaward (and simultaneously eroding underlying rock), (2) on-shore currents and translatory wave action, carrying material landward, and (3) currents alongshore. Fenneman stated that "The normal profile of a shore where the resultant of transporting power is outward is a compound curve, which is concave near the shore, passing through a line of little or no curvature to a convex front." He also indicated that the same profile would result from the reverse situation, where the resultant of transporting power was landward. By adding the convex front to Gilbert's wave cut bench-wave built terrace concept, Fenneman completed a model which was not to be challenged for years.

Fenneman reasoned that the concave-convex profile resulted from wave energy distribution, with the most energy available in shallow water at the shore and decreasing amounts occurring seaward until wave base is reached where energy is nil. Wave base, which decides the depth at which the deep water profile formed by deposition of material intersects the original bottom, was said to be at 100 fathoms off the Atlantic coast of the United States. Some currents were credited with being capable of transporting materials deeper than wave base, however, and transportation in suspension might also occur. Fenneman assumed that cutting would continue until wave base was reached, regardless of the structure or hardness of the underlying material. Modern researchers have consistently reduced the depth of wave base, until it is now felt that normal effective wave action is limited to a depth of about 30 feet, 1/20 of Fenneman's value, (Bradley, 1958).

The "profile of equilibrium" concept proposed by Gilbert and Fenneman was almost universally accepted by workers in the early 1900's. For years, strict adherence to this concept forced investigators to conclude that breaks in this "normal" profile such as shore platforms could only be emerged features and thus indicators of relative sea level change. Bartrum, Jutson and others repeatedly attacked this view and shore platforms gradually became accepted as parts of the revised contemporary profile. The present consensus among coastal workers seems to be that the Gilbert-Fenneman profile of equilibrium is a generality which is contradicted by numerous exceptions on the coastlines of the world.

W. M. Davis - Mentions Wave Abrasion as an Agent of Marine Erosion.

About the same time, at the turn of the century, William Morris Davis was publishing many articles pertaining to coastal geomorphology. He devoted little space specifically to shore platforms but did write of the abrasive powers of waves in the breaker zone. Davis (1896) considered that marine abrasion, if active in an area at all, merely put the finishing touches on a landscape shaped by sub-aerial denudation. He contrasted this view with that of the older, English concept of widespread marine abrasion as an agency for the production of broad plains of denudation.

J. A. Bartrum - "Old Hat" Platform Disrupts Fenneman's Normal Shore Profile.

In 1916, J. A. Bartrum of New Zealand published the first of a long series of papers on the subject of shore platforms. The work was entitled "High water rock platforms; a phase of shoreline erosion" and was concerned with describing and accounting for the shore platforms on "Old Hat" Island near Russell and other features near Auckland, New Zealand.

Bartrum's long continuing interest in shore platforms was apparently sparked by that peculiar formation in the Bay of Islands which Dana had remarked upon sixty-five years previously. The "Old Hat" as described by Bartrum is a coastal form carved from an emergent knob on a drowned spur, supporting a rock platform which constitutes the rim. This and similar platforms on many parts of the coast around Auckland and to the north are barely covered by mean high tides and vary in width from a few feet to thirty yards or more. Their surfaces are essentially horizontal, with a few irregularities, while seaward margins descend steeply for a few feet. Bartrum pointed out that their presence disturbs the normal shore profile proposed by Fenneman, disrupting the smoothly flowing concave-convex curves.

The shore platforms observed by Bartrum occurred under similar conditions of wave energy, rock type and coastal profile. Bartrum set forth these conditions more specifically as (1) fairly weak wave attack; (2) rock which is moderately erosion resistant and uniform textured, subject to comparatively ready decomposition; and (3) a coast which has not reached maturity of outline. In later years Bartrum found platforms which formed under different circumstances, (high wave energy, for example) and refuted the conditions listed above. Still later he justified his earlier findings by recognizing two separate types of platforms and reinstated the conditions describing the "Old Hat" type feature. Given the three conditions enumerated above, Bartrum continued, platforms will form on undestroyed headlands and stacks with no regard for the structure of the constituent rocks.

Bartrum explained that the origin of the shore platforms was due chiefly to the protection of rock from chemical decomposition afforded by water saturation. He claimed, furthermore, that platforms are due more to the destruction of cliff faces by sub-aerial erosion than to wave attack on a zone of weathered rock. Mere wave attack on weathered rock which has been submerged would form a Fenneman type profile of equilibrium. The platform could only grow when the previously weathered material had been removed and sub-aerial erosion had reached fresh rock. Then, as the cliff retreated, the saturated rock would remain as a platform. Weak wave action would function to carry away waste material, although strong wave activity might actually destroy the platform and restore the normal profile of equilibrium. Carving of the shore platforms, Bartrum points out, must take a long time and would necessarily be accompanied by the creation of cliffs of moderate height. That these cliffs occur in the area studied supported his hypothesis.

This paper was a big step forward in solidifying the speculations of J. D. Dana in 1849. Dana suggested a "level of greatest wear" and saturation as protection from weathering, but was vague about the mechanics of actual platform formation. Bartrum, building on Dana's ideas, presented a hypothesis which is still generally accepted as the formative process for the "Old Hat" type of platform.

D. W. Johnson - Explains Abrasion to Wave Base.

Three years after Bartrum's 1916 article, Douglas W. Johnson released his comprehensive book "Shore Processes and Shoreline Development." Although he discussed many shore features in this work, Johnson made few direct references to shore platforms. Wave cut benches were mentioned and related to Fenneman's profile of equilibrium, but these were large features, miles in width. Johnson included pictures of shore platforms in the book and subsequently ignored them while pointing out attendant stacks and arches. He apparently felt that shore platforms were merely exposed, continuous parts of his "wave cut bench" as he stated on page 281, "In front of the cliff low tide may expose a bare rock platform representing the landward edge of the marine bench upon which the occasional stacks are situated." Johnson may have purposely wished to avoid the subject of shore platforms, however, as a passage on page 221 reads "Long articles have been written, extended discussions have been carried on, and numerous erroneous laws of shoreline activity have been laid down, all based on observations of minor fluctuations in the shore profile of equilibrium. This has been unfortunate for the development of that part of the science of physiography relating to shorelines.... It has concentrated attention on the less important details of shore activities, and caused a neglect of the broader and more fundamental aspects of coast erosion."

In writing about the wave cut bench and accompanying sea cliff, Johnson attributed erosion to abrasion by wave powered tools derived from the cliff, with material being transported by undertow. He disagreed with some previous authors in stating that marine planation may be possible without coastal subsidence and may continue until wave base (-600 feet) is reached. In contrast to the beliefs of W. M. Davis, Johnson felt that sub-aerial erosion of sea cliffs was far less important than direct wave attack in the process of planation. Gilbert, Fenneman and Johnson had great and lasting influence over the field of shore platform study through their insistance upon submarine abrasion as the chief coastal eroding force.

DIFFERENTATION OF PLATFORM TYPES AND MORE DETAILED ANALYSIS OF FORMATIONAL PROCESSES - 1924 to 1926

J. A. Bartrum - Describes Storm Wave Platforms.

In 1924, the second of J. A. Bartrum's contributions to the shore platform literature appeared. The article was entitled "The Shore Platform of the West Coast Near Auckland; Its Storm Wave Origin." Bartrum visited the west coast of New Zealand after he published his first paper on the Bay of Islands region and found platforms on the more exposed coast which were quite different from the sheltered "Old Hat" type. The western platforms continued for long distances around headlands as a narrow bench ten to thirty feet wide, much narrower than the "Old Hat" type features. Another variation between the two occurrences was the relative height above sea level. "Old Hat" platforms are slightly below high tide level, while the western, exposed types were approximately two feet above high tide.

Bartrum was puzzled by the new type of platform, but was heartened to find that it was not identical to the "Old Hat" form. He felt that the west coast platforms were definitely of storm wave origin and if they were similar to the Bay of Islands features his formational hypothesis must be in error. On page 494 he stated, "On casual inspection this platform resembles those described by the writer from the sheltered shore lines of the harbours near

Auckland, and appears, therefore, to discredit his hypothesis of origin of these latter,....for the west coast platform is undoubtedly due solely to wave-erosion upon resistant rock." It was not until 1926 that Bartrum made a clear statement that both formational processes were possible, depending on the wave environment.

The immense power of storm waves tumbling towards the cliffs greatly impressed Bartrum and led him to postulate on page 495, "They (storm waves) rise several feet above normal water level as they travel onward as mighty waves of translation in the shallower water near the coast. They are less impeded, and therefore more effective erosive agents, when the tide is nearing flood, (the mean tidal range was thirteen feet in this area), and for this reason one may well expect them under special circumstances to maintain a cut bench of the character described above the level of the normal zone of wave attack." Bartrum thus described a process which has had many supporters through the years, provoking arguments even today. Many workers, such as K. O. Emery, later discounted the theory on the basis that storm waves should not cut high level platforms at all, but, because of their size erode to a greater depth.

Bartrum also considered the possibility that the platforms might have been formed by uplift, but rejected the idea on several grounds. He surmised that the widespread distribution of the features, combined with the approximate horizontality of the platforms, were difficult to explain in terms of uplift; particularly since the horizontal platforms failed to fit into profiles of equilibrium as defined by Fenneman and Johnson. Furthermore, sheltered Manukau Harbour in the same region supports no similar features. In accepting storm wave erosion as the explanation for the exposed platforms, Bartrum indicated how his thinking would be biased for the next thirty years.

C. K. Wentworth and H. S. Palmer - Note Eustatic Bench in the Pacific and Discuss Sub-aerial Weathering.

Another paper appearing during this period indicated the future trends of thought for a contributor to the shore platform literature. In 1925, C. K. Wentworth and H. S. Palmer published an article entitled "Eustatic bench of islands of the North Pacific." They described a bench from four to twelve feet above mean sea level which "exists on all the islands of the Hawaiian chain, without exception." This bench is best developed on tuff cones and is generally from ten to thirty feet wide, reaching extreme widths of one hundred and fifty feet. The authors noted that the bench appeared to be consistently higher on promontories and lower in bays or sheltered areas. A negative shift of sea level of twelve to fifteen feet was cited as the reason for the presence of the benches, cut under water by abrasion and subsequently emerged.

This paper was noteworthy for two reasons. Wentworth and

Palmer were among the first to document the extremely widespread occurrence of the "Eustatic bench" in the Pacific. In years to follow, many researchers were to conjecture on the origins and meanings of this feature. More significantly, the article contained Wentworth's first mention of the "Water-Level Weathering" process. On page 525, the authors stated, "In places where the bench is cut in tuff it may be so level for a considerable area that no point of the tuff surface departs more than four or five inches from a mean level.....We suggest that these 'water-level" portions of the bench are due to intensified weathering in the zone extending a few inches above and below the water level of the pool. The combined work of water and air in the zone which is exposed alternately to each seems analogous to the more rapid rotting of posts, piles and other wood structures at soil or water lines. If this process be operative, any portions of the wave-cut bench now exposed above sea-level, but in reach of dashing spray and sufficiently enclosed to contain incipient water pools would become the sites of larger and larger pools, as abrasion followed the 'water-level weathering."

At the time this paper was written, Wentworth was still accepting the generally held view that shore platforms were produced under water by abrasion and subsequently exposed by a change in relative sea-level. Later, in the 1930's, he became convinced that many of the platforms were contemporary features and water-level weathering was joined by numerous other processes to explain platform formation and levelling.

J. A. Bartrum - Explains Platform Types and Expands Formational Theories.

In 1926 J. A. Bartrum published another article on shore platforms. Prior to this time his papers had been printed in the Transactions of the New Zealand Institute and the Report of the Australasian Association for the Advancement of Science. Now Bartrum expanded his readership by publishing in the Journal of Geology. His article, entitled "'Abnormal' Shore Platforms", was a summary of his previous two papers combined with a discussion of the relationship of shore platforms to Fenneman's profile of equilibrium.

Bartrum recognized the two distinct types of platforms which he had described previously and solidified his thinking on the conditions leading to their formation. He concluded on page 806 that "....a certain broad horizontal shore platform typified by the Old Hat at the Bay of Islands may develop in sheltered waters quite independent of rock structure. It originates primarily as a consequence of progressive weathering of the sea cliffs down to the level of the platform, which is slightly below that of normal high water. There is also another type of "abnormal" shore platform that is not dependent upon rock structure for its existence; this is a narrow bench at the base of steep sea cliffs at a height which approximates normal high-water level but may be a foot or two above it. It is developed only in relatively exposed situations. Its carving is ascribed to vigorous storm-waves, which have their maximum efficiency as erosive agents near times of high water."

Bartrum thought that the shore platform response in a storm wave environment was very dependent upon the type of rock present, in contrast to the Old Hat type platform where rock characteristics were less critical. Platforms on the exposed coasts, to be uniform, were necessarily cut in highly resistant homogeneous, unjointed rocks. If these conditions were not met, the platforms would tend to be highly irregular.

The "normal" profile of equilibrium came under fire in this article. Bartrum's view was that Fenneman and Johnson were too restrictive in their thinking and allowed no room for variations in the profile. He argued that both types of shore platforms which he had described should be considered as normal parts of the profile of equilibrium where conditions were favorable for their formation. Bartrum ended his discussion of storm wave platforms with the statement on page 806, "It is urged that these platforms be regarded, not as abnormal developments of a retrograded shoreline, but as the expectable and by no means uncommon products of wave erosion."

EMPHASIS ON STORM WAVE EROSION - 1928 to 1933

J. A. Bartrum and F. J. Turner - Discuss Storm Waves and Sub-aerial Weathering.

Bartrum again appears in the literature two years later, in 1928. This paper, co-authored by F. J. Turner, indicates the development of Bartrum's thinking on the genesis of shore platforms. Only a short section of the article (entitled "Pillow lavas, peridotites, and associated rocks from Northernmost New Zealand") actually deals with shore platforms, but the paper does contain a brief mention of the process which Wentworth (apparently unknown to Bartrum) had tentatively named "water-level weathering".

The shore platforms of the area were described as in the 1926 paper and were similarly ascribed to the action of storm waves. Bartrum departs from his previous articles by stating that "there appear to be grounds for the belief, however, that sub-aerial processes active upon the wave-cut platforms have contributed very materially to the remarkably level nature of the benches of the present area, more especially where they have been developed in the more shattered rocks". Bartrum apparently planned to treat the process more fully in a subsequent paper, but it was not until 1935 that he expanded upon this subject. In that year he wrote on the efficiency of wetting and drying cycles as agents of weathering and in 1936 added salt crystallization and chemical action.

J. T. Jutson - Proposes Storm Waves as Platform Producers.

J. T. Jutson, who almost matched Bartrum's prolific literary output, first published on shore platforms in 1931. He seemed to have been unaware of Bartrum's work at that time, however, and developed a storm wave theory of origin without considering the levelling influence of weathering. Jutson's comments on shore platforms are confined to several pages of a twenty-three page article concerned chiefly with evidence for a recent uplift of the floor of Port Phillip Bay near Melbourne, Victoria. He felt that a wave-cut platform which was now above the zone of wave activity would be a good indication of relative uplift and set out to study the platforms on the coasts near the bay which were exposed to the open ocean. During his observations, Jutson, as Bartrum had done previously, discovered platforms in dune limestone and basalt which did not fit into the "normal" profile of equilibrium. The features were 100 to 200 yards wide, horizontal or sloping slightly seaward and exposed at low tide.

The possibility that the platforms were carved at another level and then uplifted to their present position was ruled out by Jutson. He reasoned that it would be a great coincidence that the platforms should be uplifted uniformly to low water mark. Jutson proposed additional arguments against uplift and remained convinced that the features were formed with relative sea level as at present.

By discounting uplift, Jutson was forced into developing a formational theory for the observed conditions. He consequently postulated storm wave formation of the platforms with attendant cliff recession as the process of levelling, but failed to explain why the features occurred just at low tide level. Jutson then tentatively advanced a theory to account for his observation of another lower platform at the bottom of the seaward edge of the low tide platform. He wrote that the possibility existed that two platforms could be formed simultaneously: a high level platform cut horizontally and a low level platform which would correspond to the normal profile of equilibrium.

Relative sizes and positions of the platforms depended on various conditions, for example, on page 148, "If the land were comparatively low and the rocks 'soft', the formation of the high-level platform might be faster than that of the low-level one, and hence the two platforms, at least for a time, would be found. Increasing height of the cliffs or a change to 'hard' rocks, or the occurrence of both these factors, would slow down the formation of the high-level platform, and permit the lower one to gain upon it. Ultimately, the higher one might be completely overtaken and disappear. If the land were high and the rocks 'hard', the high-level platform might be destroyed as soon as a few feet in width of it were formed. Hence, only one platform - the low-level one - would be regarded as forming, although, in reality, both would be formed, but the high-level one would be almost immediately destroyed."

This statement served Jutson for many years as the basis of his thinking on shore platforms. In following papers he writes of two and sometimes three platforms forming simultaneously in an area, usually by the process of abrasion and, later, by wave quarrying. In 1949, Jutson added water-layer levelling to his list of formational agents to update his theories.

D. W. Johnson - Gives Further Support for Storm Wave Formation Theory.

Douglas Johnson, also publishing in 1931, joined Jutson and Bartrum in advocating storm wave origins for the numerous Pacific benches. Johnson visited Australia, New Zealand, Japan, Hawaii and California in 1929 and 1930 "for the purpose, among other things, of studying the significance of this highly interesting wave-cut platform". Apparently the increasing interest shown by other workers in the field of shore platform study had prompted Johnson to re-consider his views on the usefulness of discussion about these features.

The main theme of the paper was a refutation of the view, widely held at that time, that the present position of benches indicated a recent change in the relative levels of land and sea. Johnson stated on pages 159 and 160, "Comparatively few have been so venturesome as to question the usual textbook explanation of wave-cut platforms (previously advocated by Johnson himself), and to suggest that the true two-meter bench might be formed at the level at which we now find it.....The thesis supported in this paper is the following: wave-carved platforms normally have their inner margins from a few centimeters up to two meters or more above the level of ordinary high tides, the exact level varying with conditions of exposure to storm waves, tidal range, breadth of platform and other local conditions. The cutting is effective in unweathered rock, and usually is independent of the ground water level. As the inner margin is cut farther into the land, the outer portion is worn deeper by long-continued abrasion, and eventually is reduced below sea level. The platforms, therefore, slope gently seaward beneath the water, or may give place to lower platforms due to secondary wave cutting below the major storm level."

Johnson considered the characteristics of breaking waves in justifying his argument. He wrote that the benches were formed at the present high level for several reasons. Firstly, because in waves of oscillation the crests rise farther above still water level than the troughs sink below that level, the most effective attack will occur above mean sea level. Waves of translation, with almost the whole body of the wave above still water also had this property. Johnson added that these effects would be enhanced by the piling up of water driven by storm winds. He also said that the water was propelled up the "normally sloping" abrasion platform to higher elevations than if the platform were horizontal.

Abrasion, both by debris powered by wave action and a "hydraulic sheet" of unarmed pure water launched across the platform by a breaking wave, was cited as the platform carving mechanism. Johnson claimed that the rock structure would be a controlling factor in platform morphology when differences in resistance were present and that only where the differences in resistance were not great, as in volcanic ash beds, would the platform bevel indifferently across the inclined layers. The only mention Johnson made of weathering was a slightly derogatory remark in reference to previous reports of emerged platforms. He stated, "But the critical observer can usually discriminate the typical 'two-meter bench' (as it has come to be called because of its more usual upper limit above high tide) from differential weathering platforms and other non-marine features."

Through an exercise in logic, Johnson assembled a case for the formation of the "two-meter bench" with present conditions. Johnson proposed that if the bench is a product of present conditions, there would be good evidence of the frequent presence of waves on the platform. He then went on to cite examples of locations where this occurred. Another proposition was that if the two-meter bench was the product of storm waves, then the benches should be higher where exposed to large waves and lower in more sheltered locations. Again he listed locations where he encountered this condition, but failed to consider factors such as saturation control over weathering. In general, Johnson was more successful in presenting the argument for contemporary formation than he was in giving a convincing explanation of storm wave erosion.

D. W. Johnson - Reinforces Storm Wave Formation Theory.

D. W. Johnson elaborated on some of his statements concerning erosion by storm waves in a paper published two years later. In 1933, an article entitled "Role of analysis in scientific investigation" appeared in the Bulletin of the Geological Society of America. This publication was an expansion of an address given by Johnson to the American Association for the Advancement of Science concerning the methodology involved in scientific investigation.

To illustrate the use of multiple working hypotheses in research, Johnson developed his ideas on the storm wave formation of platforms. He paused before starting this discussion of formational factors to give a working definition of a shore platform as "(A bench) lying close to the present shore, ranging from one or two feet to five or six feet only above ordinary high tides, showing fresh rock surfaces usually free from debris." (Page 479).

Johnson then suggested that the mere impact of water, not necessarily armed with debris, could form the platforms. Listed as important factors were: "The terrific impact of the water itself, the force of the currents it generates, the direct pressures exerted upon air in crevices and pore spaces when the rapid retreat of a wave creates a partial vacuum outside, all these are described as effective causes of damage by waves....while shore debris is presumably a highly important factor in wave erosion, there is no reason to exclude the possibility that waves relatively free from debris, and striking with a force varying from hundreds to thousands of pounds per square foot, may accomplish much erosive work". (Page 484).

Johnson's explanation seems plausible for the formation of a notch in a cliff face, but he fails to show why an extensive, almost horizontal platform rather than a distinctly sloping surface should result from this type of wave activity. The "multiple" working hypotheses" were few in number and completely ignored such factors as weathering, solution and biological activity. As in the 1931 paper, the case was more persuasively presented for contemporary formation of the platforms than for storm wave carving. That Johnson felt the need to continually emphasize the contemporary nature of shore platforms indicates how general the belief in under-water formation by abrasion followed by sea-level change was at that time.

TRANSITION TO THE MODERN PERIOD - 1935 to 1936

J. A. Bartrum - Discusses Wetting and Drying; Salt Crystallization.

In a 1935 paper, Bartrum reviewed his previous work on storm wave and "Old Hat" platforms and added further to the hypothesis of secondary sub-aerial planation first mentioned in 1928. Aside from a slightly more detailed discussion of the conditions needed for effective wave planation (i.e. shallow water offshore to prevent clapotis), the review yielded little new information. The chief value of the paper lies in the mention of wetting and drying cycles, coupled with salt crystallization as agents of platform levelling.

Bartrum still credited storm wave action with the initial cutting of the high platform, but used the level of saturation as a determining factor in the extent of sub-aerial lowering. He felt that this level of saturation would be highest on the seaward edge of the platform, producing what Wentworth would later call a rampart. The rampart proved troublesome for Bartrum because, "when theory is confronted with fact, it is found that this feature is by no means ubiquitous, though it is not uncommon. This may often be explained as a consequence of lack of response of the rocks to sub-aerial weathering, but other explanations are demanded at other times. Indeed, it must not be imagined that all platforms should show the effects of what is here regarded as a process of sub-aerial levelling. A definite combination of conditions is clearly essential: the tidal range and other factors must combine to allow alternate wetting and drying, whilst the rocks concerned must be amenable to disintegration in consequence of this alternation...." (page 142).

Bartrum had now explained in broad terms the factors leading to platform development and had pointed out the need for a better understanding of the specific weathering processes involved. In a 1936 paper he developed this theme further with a general discussion of honeycomb weathering in rocks. Bartrum attributed honeycomb weathering, which might take place in arid regions as well as coastal environments, to repeated salt crystallization and chemical action. He stated that jointing in the rocks was important in controlling the distribution of pitting because of the resistant nature of iron oxide cement filling the cracks. Bartrum credited scour by sand laden wind or swirling water as being useful in removing weathering products, but not necessary to the honeycombing process. As Bartrum grappled with this problem he became increasingly aware of its inherent complexities and was still unable to completely isolate the processes involved. Interest in this study began to grow, particularly with workers in the Pacific area, but the problems proved highly resistant to even concerted attack.

H. T. Stearns - Recognizes Compexities of Shore Platform Formation, Shows Influence of Organisms.

An addition to the shore platform literature was made in 1935 by H. T. Stearns, a United States Geological Survey geologist working in the Hawaiian Islands. He identified and critically examined a number of "benches" at various locations and heights above present sea level, but was primarily interested in two platform types which were in the process of formation. These corresponded roughly with the "Old Hat" and storm wave features which Bartrum and others had described previously.

Stearn's "lower bench" is a platform which is seldom awash at low tide and which may occasionally reach widths of over fifty feet. He believed that solution and boring organisms might be important factors of the formation of this bench, as the best developed features occurred on lime cemented tuff and limestone, both of which were commonly pitted by shellfish.

In recognizing solution and biological activity as factors in shore platform formation, Stearns showed that the platforms were more complex than Johnson and others had supposed. Stearns was not a complete radical, however, as he still favored wave action as the most active agent.

The other platform mentioned by Stearns, the "upper bench", was more difficult to describe in terms of occurrence and formation. He wrote that the location and characteristics of wave-cut benches were determined by many factors, including the degree of exposure to wave attack, the height of the tide, strength, bedding and solubility of bedrock, the number and type of marine boring organisms, amount of abrasives present, and protective marine plant cover. The upper bench was postulated as being formed by storm wave activity when factors were favorable. Stearns felt that, while the storm waves were important in forming a platform, sub-aerial weathering should also be considered as a significant process.

Stearns, like many other advocates of storm wave abrasion as a high level platform producer, fails to adequately explain the method involved and readily admits that some cases do not fit into the theory. He reports one instance of a high level and low level platform occurring in the same rock (a tuff) separated by a resistant dike. The high level platform is constantly exposed to the pounding of large waves while the low level feature is in sheltered water. Stearns believed that both levels were being actively produced with the sea at the present level, by wave activity, but declined to be more specific. As mentioned above, he felt generally that weathering might be important even though he omitted any mention of saturation as a control over horizontality.

With the recognition of several types of platforms and numerous factors in formation, Stearns outlined the course of future shore platform study. Early writers had treated shore platforms on a fairly limited scale and in a very few localities. Their chief aim was to describe the novel features and to propose simple formational processes on the basis of their own observations. There was little or no contact among workers in the field and apparently scant interaction with other disciplines. Through the years more insight was gained into the problem and, as usually happens in the scientific development of a subject, apparently simple processes revealed their true complex natures. In the middle 1930's, as shown by Stearns' paper, the study of shore platforms progressed into the relatively more sophisticated modern stage, where platforms were actually measured and formation examined in detail.

Chapter 2

THE PERIOD OF MEASUREMENT - 1938 to Present

PROFILE MEASUREMENT AND WATER-LEVEL WEATHERING - 1938

C. K. Wentworth - Surveys Platforms and Proposes Water-Level Weathering Process.

In 1938, C. K. Wentworth published an article which marks the beginning of the modern phase of shore platform research. Prior to this time, workers had been content to describe shore platforms in vague terms, with elevations in particular very loosely defined. Expressions such as "exposed at high tide" or "continually awash" often occurred in the literature. Wentworth saw the need for more precise data and conducted a platform measuring program in Hawaii with the aid of surveying instruments.

From this field research, Wentworth recognized four chief processes forming or modifying benches on the Oahu coastline. These were water-level weathering, solution benching, ramp abrasion and wave quarrying. Wentworth planned a series of articles, starting with a description of water-level weathering, but the war interrupted this systematic development and only the first two papers in the series were published. Douglas Johnson was apparently impressed by Wentworth's water-level weathering presentation for it was the lead article in the first issue of the Journal of Geomorphology.

Although still not the last word on platform genesis, the articles were widely discussed and remain basic reading for the student of shore platforms.

Wentworth's first paper presented the hypothesis that a process called "water-level weathering" acts to level platforms at elevations from two to twenty feet above present sea level. He emphasized that this weathering was levelling emerged benches previously cut by quarrying or abrasion and was not a primary bench producer. Wentworth went on to state that these benches could be used as qualitative indicators of emergence, but that quantitative measurement was not possible. He felt that this difficulty arose because the bench height tended to approach a state of equilibrium with contemporary sea conditions, with the result that the surface was lowered an unknown amount from a previous level. Tuff usually showed the best expression of water-level weathering, although some sub-aerially weathered dike complexes were also affected.

The formation of a ridge or rampart at the seaward edge of the platform was considered by Wentworth to be a common and possibly necessary characteristic of water-level weathering. This rampart is a remnant of the original bench level which weathers more slowly because it undergoes fewer wet-dry cycles. Ponding of water behind the rampart may allow large areas to be weathered to the same level, producing an extensive platform. Weathering, Wentworth stated, was slow on the rampart, but could continue until the rampart reached the same level as the rest of the platform and lost its damming capability. At this time the entire platform might experience a rejuvenation of water-level weathering and subsequently be lowered. Even on the rampart, the most exposed location, Wentworth detected no sign of abrasion or wave quarrying competing with the water-level weathering processes.

Wentworth was uncertain of the exact nature of the weathering mechanism but described it broadly as a physical process akin to the slaking of shales when exposed to water and with rock pressure released. He stated that surface tension phenomena, colloidal and dilation behaviours and recrystallization of salts may be important weathering agents in the shore environment. The original pits or depressions are usually created by differential weathering in areas exposed to waves or heavy spray, although sea urchins are also active in initiating hollows. The depressions are enlarged primarily by weathering of the repeatedly wet and dry walls, with limited activity on the floors. An essential factor in the process, Wentworth stated, was the removal of debris by periodic wave action. He concluded that benches produced by water-level weathering would be higher on exposed coasts than on sheltered coasts for the same reason that a rampart often remains in front of the lowered platform.

The water-level weathering process, described as capable of platform levelling at considerable heights above sea level, was a challenge to the proponents of storm wave formation theories. Wentworth took a direct swing at the storm wave supporters with the statement on page 26 that, "It is unthinkable that the level bench has been shaped by mechanical action of waves first moving over the higher rampart."

J. A. Bartrum - Agrees with General Water-Level Weathering Mechanism, But Questions Alleged Minor Role of Storm Waves.

Response to Wentworth's article was almost immediate. First to rise to the defence was John A. Bartrum, writing in the next issue of the Journal of Geomorphology. Bartrum started off by agreeing with the general process of water-level weathering, but quickly took Wentworth to task over the importance of storm waves in platform formation. New Zealand features which Bartrum had studied were cited as examples of the contemporary high level storm wave platforms of which Wentworth had denied the existence. Bartrum did allow Wentworth some room to manoeuvre by considering the effects of the tidal range and storminess of the adjacent seas. The Tasman Sea off New Zealand, with an eight to eleven foot tide and notoriously stormy habits, was compared with the North Pacific, which has a low tidal range in the Hawaiian Islands. Bartrum felt that these differences might account for the observed variations in platform morphology in which case "Dr. Wentworth's reasons for regarding the Hawaiian platforms as probably indicating some change of sea level may therefore be sound." (Page 267). Bartrum also pointed out that Wentworth had failed to mention the important influence of saturation in the determination of the ultimate level of the platform. Wentworth was indeed hazy about the limits to which his process would operate and Bartrum's criticism was valid.

D. W. Johnson - Criticizes Terminology But Generally Supports Process.

Douglas Johnson also took the trouble to comment on Wentworth's article in the same 1938 Volume of the Journal of Geomorphology. Johnson generally agreed with Wentworth's views, but suggested that the name "water-level weathering" should be changed to avoid confusion with terms referring to sea level. In addition, Johnson reminded his readers that Bartrum had described a similar process in 1935 which was distinct from the "Old Hat" type of weathering. This seems to be a gentle chiding of Wentworth for his failure to credit Bartrum for his previous work, or for being unaware of it completely. However, to show his impartiality, Johnson immediately sided with Wentworth in his statement that wave cutting was an essential factor in bench formation. Johnson felt that Bartrum's arguments for the creation of shore platforms by weathering alone were unconvincing.

Johnson seemed to be using this discussion to air quite a few of his own beliefs at the expense of Bartrum and Wentworth. He next attacked Wentworth's rampart by writing that it was probably not a result of differential weathering of similar rock but, where it occurred, owed its existence to more resistant rocks. Johnson had inspected these ridges on the Oahu platforms and concluded that, "So many well developed shore benches show nothing resembling a marginal ridge that it seems difficult to admit the rampart as an essential factor in bench formation". (Page 272). In his summary paragraph, Johnson relented a bit and applauded Wentworth for "centering attention on a process which may have played an important role in shore development".

C. K. Wentworth - Proposes Solution Benching Process.

In the next year, 1939, C. K. Wentworth published the second article of the planned series. This article, entitled "Marine Benchforming Processes; Solution Benching", was also printed in the Journal of Geomorphology. Solution benching was compared with water-level weathering (the name was unchanged in spite of Johnson's criticism) as a process by which levelling was accomplished through quiet aqueous action. Wentworth explained that the similarity between the two processes ended here, however, and that many differences existed between them. Water-level weathering was basically a mechanical (though not abrasional) mechanism operating on tuffs, while solution benching occurred chemically in reef limestone.

The features produced by solution benching were described by Wentworth as very level benches, mostly two or three feet above sea level and up to thirty feet wide by several hundred feet long. A distinct pitted zone was mentioned above the solution bench, which represented an area of active solution. The inland edge of the solution bench itself often took the form of a nip and overhanging visor. None of the features showed any sign of mechanical abrasion to account for their morphology.

Wentworth reasoned that the shaping of these features was due to solution by fresh or relatively fresh water. He ruled out sea water as a solvent because of its known saturation with $CaCo_3$ and built his theory on the basis of a good supply of rain or ground water being available at the shore. Wentworth had pondered over the influence that organisms in pools might have over solution by salt water, (later to be studied by workers such as K. O. Emery), but abandoned that line of enquiry in favor of solution by fresh water. He wrote that control over the level of the bench was exerted by the influx of saturated sea water by wave and splash which inhibited solution below a certain level. Tests on the benches had shown increasing salinity as the lower levels were approached. Wentworth calculated that with the twenty five inch per annum rainfall of the limestone coasts of Oahu, horizontal widening of the bench by solution would take place at the rate of one foot every five thousand years. He went on to comment that the widths of existing benches seem to demand much more rapid formation than this, but did not discuss the matter further.

With his two articles, Wentworth had outlined some of the complexities of platform genesis. He called attention to processes which competed with the classical wave abrasion mechanisms and forced workers who regarded every shore platform as an emerged feature to re-examine their thinking. Wentworth's work has remained relatively unscathed by new developments through the years, although others have embellished some of the facets. Following is a summary of the two processes, water-level weathering and solution benching, which appeared on page 21 of the 1939 article:

Characteristic	The Water-Level Bench	The Solution Bench
Kind of Rock	Chiefly tuff; weathered dike complex in places.	Reef limestone, less distinctly detrital limestone.
Elevation	Mostly five to fifteen feet. Small patches to twenty five feet.	Mostly two or three feet; with only small areas to five or six feet, very exceptionally.
Area	Ten to thirty feet wide generally, up to several hundred feet long.	Ten to thirty feet wide, to several hundred feet long.
Levelness	Local variations of a few inches only.	Only one or two inches variation, except as terraced by algal rims.
Rugged, etched rampart zone	Typically present.	Wholly missing, not essential to process.
Inland margin	Nip and cliff.	Pitted zone, with or without nip.
Prevalent water condition	Water maintained in pools, but large areas often dry.	Whole bench washed, small areas rarely dry.
Organisms	No algae generally on bench; small fish and invertebrates in pools.	Luxuriant growth of algae, with fish and variety of invertebrates.

AUSTRALASIAN STUDIES - 1939 to 1940

J. T. Jutson - Names Platform Features and Favors Formation by Storm Waves.

The *Journal of Geomorphology* in its short life had become a focal point for shore platform literature and in 1939 published an article by J. T. Jutson of Melbourne, Australia. Jutson, who had previously (1931) written of platforms near Melbourne, now turned his attention to the coast of New South Wales. Here he found the same two types of platforms which he had encountered in the south, but also discovered a higher feature which he called the high-level platform. As previously, he ascribed the cutting of the underwater "ultimate platform", the periodically exposed "normal platform and the usually dry high-level platform" to wave abrasion. Jutson invoked storm wave formation for the highest level platform and combined this process with ordinary wave action to explain cutting on the normal and ultimate platforms.

Little was said of the ultimate platform other than that it is always submerged and has a sloping contact with the higher, normal platform. It would appear to be analogous to Fenneman's profile of equilibrium, although Jutson mentions that other levels of platforms may exist in even deeper water.

Jutson treated the normal platform in more detail and described it as having a level surface located a foot or two below high water mark. The usual width is fifty to one hundred feet, although an immense platform is mentioned which is two hundred yards wide and a half mile long at Long Reef. The features which Jutson studied were cut in horizontal or gently inclined shales which were jointed and apparently differentially resistant. In some cases the platforms bevelled the inclined beds, but elsewhere followed the bedding. As Wentworth had observed in the Hawaiian Islands, some of the horizontally bedded features were being lowered in patches to "sub-normal" platforms.

The uppermost bench occurring in the area was the high-level platform. This, Jutson explained, resembled the normal platform except for its width - the high-level platform is usually only a few yards wide. Its average height is three feet above the normal platform, but great variations occurred in individual cases. Some parts of the platform are awash at high tide and the entire platform may be swept by storm waves. The seaward edge of the high-level platform is being eroded in the formation of the normal platform by marine action. At the same time, the high-level platform is extending landward at the expense of the cliffs.

Jutson further delineated shelves and ledges as features common along the New South Wales coast. These were located above the high-level platform and had average widths of twenty feet for the shelves and three feet for the ledges. Spray is credited with being the chief formational agent, with or without the help of atmospheric weathering.

Jutson was very impressed with the amount of work carried on by the spray from breaking waves. He expressed the opinion that the spray both eroded the soft shales directly and carried away the weathering products, exposing fresh surfaces.

Like Wentworth, Jutson felt that the features he observed could have been produced with present sea level conditions. Jutson stated that his high-level platform (similar in position to features described by Wentworth) is currently undergoing modification by abrasion, but that it may be a fossil feature. However, Jutson found no positive evidence for emergence in his research and remained satisfied that the shore platforms described were actively forming.

E. S. Hills - Shows that Emergence is Responsible for Specific Platforms.

Another member of the "Melbourne School", E. S. Hills, published a paper in 1940 concerning evidence for recent emergence in Port Phillip Bay, Victoria. Hills found considerable grounds to support a hypothesis of recent emergence in this large, landlocked bay "at practically all localities where the conditions of erosion and deposition are such as to favor its preservation." He described a raised granite platform in one area which was about three feet above high tide level. No horizontal structure existed in the granite to account for its shape and Hills attributed the feature to abrasion during a period of higher sea level although he did admit the possibility of "Old Hat" type formation.

More positive evidence for emergence was discovered in the occurrence of grass and talus covered fossil platforms. One platform, Hills explained, was cut in Tertiary sandstones at a height of about three feet above present average high water level. Raised shore platforms also have been carved in basalts to widths of about twenty or thirty yards. These platforms are not normally awash at high tide, but may be immersed by a combination of high tides and flood. A cover of grass and loose basalt boulders precludes the possibility that the platform is being formed at the present time. Hills, however, did find an apparently active abrasion platform at a level about three feet below the fossil feature.

Hills added little to the development of shore platform knowledge in this particular paper, but did illustrate the caution which is necessary in the interpretation of shore platforms as emerged features.

M. Ongley - Describes Importance of Spray in Weathering Processes.

The year 1940 yielded several more papers concerning shore platforms. The New Zealand geologist, M. Ongley, in what is probably one of the shortest articles in scientific literature, commented in that year on the importance of spray in coastal weathering processes. Ongley's complete article as published in the New Zealand Journal of Science and Technology follows:

"As the correct interpretation of coastal platforms helps us to understand recent changes in sea-level, the evidence afforded by the benches eroded by spray weathering at Castlepoint (New Zealand) is important. As shown in the photos, (showing differential erosion in beds of differing hardness), the beds fronting the sea strike parallel to the coast and dip inland. They are lashed by the big waves of the open ocean, which throw spray high up the cliff. Differential weathering under the influence of the spray is eroding benches fifty five feet and eighty feet above the sea. As seen from the pools of salt water and the freshness of the benches, these are forming in place, and do not indicate any recent uplift of the land. Accordingly, in dealing with coastal benches, the work of spray-weathering should not be overlooked."

Although this article was short, many later workers have quoted it when discussing the efficiency of weathering processes in platform formation.

J. T. Jutson - Updates Terminology and Again Favors Formation by Storm Waves.

J. T. Jutson, writing on "The shore platforms of Mt. Martha, Port Philip Bay, Victoria", also published in 1940. As in his previous papers, Jutson emphasized the production of "normal" and "ultimate" platforms in interpreting the region. He described Mt. Martha as a granodiorite dome with decomposed extremities flanking a fresh core. The platform response is closely related to the degree of rock weathering, with the normal platform absent in the undecomposed areas.

Jutson introduced the term "secondary ultimate platform" in this paper to describe an ultimate platform which is being formed by the destruction of the seaward edge of the higher, normal platform. As in previous papers, the term ultimate platform refers to the classic profile of equilibrium. Jutson noted the occurrence of the ultimate platform below cliffs in areas where the granodiorite was fresh and solid. The secondary ultimate platform and the ultimate platform were both said to be the result of combined wave quarrying and planation.

Most of Jutson's observations in this paper were centered on the extensive normal platform occurring in the weathered material. This platform measured five hundred to six hundred yards long by thirty yards wide and was largely horizontal, although it sloped five to seven degrees seaward in places. Jutson attributed the cutting of this platform to wave planation of the previously subaerially weathered material. A few shelves were also present, rising to eight feet above the normal platform in some locations. They were free of detritus and supported marine molluscs, indicating to Jutson that the sea occasionally swept the features.

Sea action was then held responsible for both primary erosion of the shelves and the removal of debris of atmospheric erosion.

This article indicated Jutson's continuing interest in the systematic treatment and classification of shore platforms. His nomenclature was fairly unwieldy, especially in the case of the "Secondary ultimate platform", but the establishment of a descriptive, correct and universally accepted terminology was (and is) a worthwhile goal.

PLATFORM CHARACTERISTICS AND FORMATIONAL PROCESSES CATALOGUED - 1940 to 1945

J. E. Hoffmeister and C. K. Wentworth - Compile Listing of Platform Characteristics and Formational Processes.

Chester K. Wentworth followed up his 1939 article on solution benching with a co-authored contribution in 1940. Joining with J. E. Hoffmeister, Wentworth produced a paper for the Sixth Pacific Science Congress in San Francisco entitled "Data for the recognition of changes of sea level."

As the title suggests, this article was concerned chiefly with the general aspects of identifying evidence for changes in sea level. However, one section dealt with shore platforms and contained a listing of platform characteristics and formational processes which was the most comprehensive produced to that date.

Wentworth considered abrasion by sand and gravel to be an effective force for platform formation, but added on page 845, "Most textbook discussions fail entirely to consider the true complexity of marine attack on the land and the variety of processes by which the position of sea level may come to be approximately indicated on the land surface......It is not believed necessarily that each of the processes named commonly produces a complete bench and cliff notch, but it is thought that each, acting on appropriate rocks and in its particular situs, does determine a characteristic element of the profile and that some, under suitable conditions, are dominant."

The factors outlined by Wentworth were as follows:

I. Mechanical Action.

A. Direct impact of waves on rock.

B. Plucking effect of wave and current movement parallel to the surface.

C. Hydrostatic effects of air or water in fissures and cracks.

D. Rill action of sea water running back down cliff.

E. Abrasion by means of sand, gravel or blocks.

II. Physical and Chemical action.

A. Disruptive effects of alternate wetting and drying.

B. Disruptive action of crystallization of salts.

C. Freezing of sea water or ground water in the rocks.

D. Freezing of sea along shore.

E. Solvent effects of fresh water from rain or run-off.

F. Chemical effects of life, or decay of organisms.

III. Organic Action.

A. Work of boring or pit-forming organisms.

B. Action of seaweeds and other binders of sand.

These factors and processes enumerated by Wentworth in 1940 are still useful as a base from which to launch a detailed examination of shore platform genesis.

A. B. Edwards - Reports on Tasmanian Shore Platforms.

In the next year, 1941, the Melbourne geologist A. B. Edwards published two papers pertaining to shore platforms. One was a regional description of the northwest coast of Tasmania which included references to the many shore platforms in the area, and the other was a systematic treatment of "Storm wave platforms".

Edwards' paper on the Northwest coast of Tasmania is of more use to the person seeking general information on the geology and geomorphology of the region than to the student of shore platforms. He reported on the occurrence of the numerous basalt platforms along the coast, but failed to attempt an explanation of formative processes.

A. B. Edwards - Lists Factors Involved in Platform Development.

Later in 1941 Edwards published an article on storm wave platforms in which he discussed the characteristics of the various platforms visited previously in Victoria and Tasmania. Unlike the previous paper, he devoted considerable space to the platform cutting process and conditions favorable for its operation.

Edwards catalogued a number of factors involved in platform genesis, covering a wide range of emphasis. Specifically, he suggested that "storm wave" platforms were restricted to coastlines of submergence or fault coastlines which are still in a stage of youth. This was required because in such conditions the energy of wave attack would be in excess of the energy required to transport all available debris. Given a coast as described above, Edwards continued, platforms would only develop where a suitable combination of wave vigour, rock hardness, cliff height and tidal range exists. For any condition of wave attack, there would be an optimum rock hardness which would give the widest development of storm wave platforms. As hardness departs from the range encompassing the optimum, storm wave platform production becomes less probable.

Rock hardness was, in Edwards' opinion, a very important parameter. He had observed that on coastlines formed of moderately hard rocks the storm wave platforms were best developed at headlands and grew narrower towards the heads of embayments. In places where wave attack was considerably weakened, Edwards found sloping wave benches at the embayment heads. A quite different situation was noted where the coastline was formed of soft rocks. Edwards postulated that wave attack might be too vigorous at the headlands for storm wave platform development, but some reduction of wave strength in embayments could encourage platform growth within.

Cliff characteristics and tidal factors interacted with rock hardness and wave conditions in Edwards' view of shore platform development. Other conditions being equal, he stated, the higher the cliffs the narrower the shore platform. Tidal conditions also have influence over the width of the platform, with wider platforms being encouraged by greater tidal range. Edwards claimed that tidal factors would influence the level at which cutting would commence on a new fault coast or one of recent submergence. Initial cutting would be at low tide level because waves would not break in deeper, high tide conditions. Eventually, however, high tide attack would become the stronger force and a storm wave platform would ensue. In all cases, Edwards concluded, abrasion was the means by which platforms were originated and levelled.

Edwards' general statements about the factors influencing shore platform development are worth considering, but some of his specific examples should be viewed cautiously. In one instance he states, "It is noticeable, also, that for a given type of rock, the width of the storm-wave platform varies with the strength of the wave attack. Thus at Cape Grim, on the west coast (of Tasmania), the storm wave platforms formed in the Cambro-Ordivician sediments are narrower than those cut in similar rocks along the north coast". The shore platforms of Cape Grim are actually cut in Tertiary Basalts.

A. B. Edwards - Notes Relationship Between Height of Cliff and Width of Platform.

Shore platforms proved interesting to A. B. Edwards, for he again published on the subject in 1942. In a description of the San Remo peninsula he mentioned platforms of up to two hundred feet in width occurring in jointed Jurassic sediments. Again he found relationships between the height of the cliffs, in this case from one hundred to two hundred feet, and the width of the platforms. Edwards also described "storm ledges" above the storm wave platform where hard bands of rock were exposed to periodic wave attack. The presence of pronounced honeycomb weathering was reported by Edwards at the cliff bases and on the storm wave platforms themselves, but received little credit for being active in platform development. It seemed to be Edwards' policy to keep genetic discussion out of his regional descriptions, at least concerning shore platforms, and the 1942 paper resembled the Tasmanian article in this respect.

C. K. Wentworth - Emphasizes Effect of Fresh Water Solution on Shore Platforms.

In 1944, C. K. Wentworth returned to the literature with an article alliteratively entitled, "Potholes, Pits and Pans: Sub-aerial and Marine". The paper reiterates Wentworth's belief that fresh water solution forms marine pits and pans down to a level where there is frequent incursion of salt water. However, he did add the level of saturation as a limiting factor to the depth of solution.

Wentworth specifically discussed potholes produced by fluviatile abrasion, sub-aerial solution pits, both sub-aerial and marine flat-bottomed pans, and marine potholes. Each of these features, he stated, occurs in a certain typical combination of variety of rock and physical and chemical condition. In some places Wentworth found two or more of the different types of depressions together, occasionally with some indication of transition from one to another. Wentworth concluded that, "In their character and their occurrence these potholes, pits and pans illustrate the principle that a locally dominant process may, with change of either place or time, lose its dominance by transition from a favourable to an unfavourable type of rock, by weakening of part or all of the physiochemical factors under which it operates, by being overmatched by some other locally dominant process, or more commonly, by some combination of these occurrences".

Although he had abandoned his plan of 1938 to systematically present a number of articles dealing with "Marine Benchforming Processes", Wentworth was still emphasizing the importance of solution in platform development.

A. B. Edwards - Points out Significance of Rock Structure in Platform Development.

A. B. Edwards published another of his regional geologies in the next year, 1945. This paper dealt with Philip Island, which is about 60 miles south of Melbourne on Bass Strait. Edwards reported that both the exposed south side of the island and the sheltered north side supported shore platforms.

All the headlands and any straight sections of the cliffs on the south side of the island were found to be fronted with "storm wave" platforms. On the sides of the headlands, Edwards pointed out, the platforms became narrow and gave way to boulder beaches in the smaller inlets and sand beaches in the wider bays. The platforms were described as being covered by the sea at high tide and, when exposed at low tide, measuring as much as three hundred feet in width. The same relationship between cliff height and platform width which Edwards had observed elsewhere occurred on Philip Island. The platforms were widest where the cliffs were low and narrowest where the cliffs had more height.

Edwards noted considerable differences in the various platforms, due in large part to rock structure and type. He detailed the occurrence of a double platform which he attributed not to Jutson's multiple level theories, but to stripping back of tuff overlying a bed of basalt which has been cut into by wave attack. The surface of the platforms, Edwards explained, often coincided with the top of a basalt flow and frequently showed a "step up" in level. This step appeared to result from the columnar structure of the basalt flow above the red band of decomposed rock or tuff separating the flows. In addition to the steps, residuals of the upper flows were seen to remain as stacks above the platform. The tuff platforms, Edwards stated, were smooth, while the basalt features were usually grooved by a network of gutterways following columnar jointing. He detected ramparts on some of the platforms, but others were level to the edge. The seaward face or nip, Edwards continued, was steep to vertical with occasional bevelling at the top. The granite next to the basalt supported no platform because, Edwards felt, the rocks were too hard to permit any appreciable low tide erosion.

Storm wave erosion still was considered by Edwards to be the most logical explanation for platform development. He did encounter a platform in basalt and tuff on the sheltered, north side of Philip Island which would have been difficult to attribute to storm wave activity, but declined to comment on its origin.

C. A. Cotton - Summarizes Views on Shore Platforms.

C. A. Cotton, the New Zealand geomorphologist, published few papers dealing expressly with shore platforms. He was familiar with them, however, and included a section on the "High-water or Shore platform" in his 1945 geomorphology text. Cotton's treatment of the subject amounted to a clear and concise summary of the current state of knowledge and no radical new theories were introduced. He tended to place equal emphasis on both "Old Hat" and storm wave formative processes, and proposed an interdependence of the two activities.

Cotton described the "Old Hat" process in calm waters as a saturation limited weathering phenomenon, but carried the thought further by stating that storm wave platforms were also formed in large part by weathering. The storm waves operated to remove debris and to actively erode solid rock, according to Cotton. Wetting and drying was favored as the weathering process most active on the platforms, and the rampart was mentioned as a form left behind as storm waves removed the more weathered, landward rock debris.

Not having any particular position to defend, Cotton was able to synthesize the storm wave and "Old Hat" formational theories into a process which may be closer to the truth than either individually. It is unfortunate for the field of shore platform study that C. A. Cotton was not more interested in the subject.

EXAMINATION OF BIOLOGICAL INFLUENCES - 1946 to 1948

K. O. Emery - Makes Preliminary Measurements of Erosion Rates, Studies Solution and Notes Importance of Biochemical and Biological Activity.

In the years following the end of World War Two, increasing attention was paid to the erosive activities of organisms. One of the leaders in this field of investigation was K. O. Emery.

Emery, a marine geologist long associated with the University of Southern California, published a paper in 1946 entitled "Marine solution basins". At least since 1941, Emery had been working on aspects of cliff retreat and platform formation. In that year he had published a note on the rate of surface retreat of sea cliffs based on the study of dates carved by contemporary, primitive Californian artists in Cretaceous sandstone cliffs at La Jolla. These dates seemed to indicate that about six years were required for the letters to be obliterated. Emery surmised that if the average depth of each inscription were one-eighth of an inch, the weathering rate would be about one foot in six hundred years. Consequently, he felt that wave abrasion was not the complete answer and set out to discover other processes modifying the rocky shorelines.

In the 1946 paper, Emery described one of the processes which he considered important in shore platform and cliff genesis.

Emery refused to accept the old belief that, because sea water was commonly saturated with $CaCO_3$, no solution of limestone or calcareous cementing material could take place. Through study of "high tide" rock basins at La Jolla and elsewhere, he found evidence to indicate that biochemical processes cause the sea water in the basins to become unsaturated with calcium carbonate at night so that solution was possible.

Emery suggested that plants and animals increased the CO_2 content of the water in tide pools by respiration. In the daytime however, the plants reduced the CO_2 content by photosynthesis. As a result, Emery concluded, the tidal basins are filled with sea water having a low pH at night and a higher pH in the daytime. The low night time pH is capable of allowing solution of any calcareous material present. During the daytime, the sea water deposits $CaCO_3$, forming resistant, elevated rims at the pool edges.

The basins which Emery studied were not distributed equally over the bench. He found them to be most numerous in the middle portions of the bench (nine to eighteen meters from the cliff), with lesser occurrences both seaward and towards the land. Emery proposed that the basins were fewer shoreward because they were in an earlier stage of development. Seaward, the basins appeared less numerous for exactly the opposite reason; a later stage of development had been characterized by widening and deepening due to coalescence of adjacent basins.

In this paper Emery also emphasized the surprising amount of erosion that the Littorina snails can accomplish. Emery pointed out that snails are very active in scraping detritus and microscopic plants from the rock surfaces during their feeding operations. He stated that snails living on a sandstone bench thirty meters wide and one hundred meters long could erode five hundred kg. of sandstone in a year. The fine grained material scraped up and excreted by the snail is ultimately carried away by wave action. The total lowering of basin floors due to all causes is estimated by Emery to be at the quite rapid rate of one centimeter every thirty three years.

Emery had brought forward a process for platform lowering which was more satisfactory than Wentworth's fresh water solution hypothesis, limited as it was in application. With his emphasis on the biochemical relationships existing in solution basins, Emery indicated the theme which his future studies on shore platforms would take. Although Emery's process was useful in explaining the lowering of an existing platform, it was difficult to see how it could create the original high level feature. Emery later postulated a recent fall of sea level to account for the original elevated feature which was undergoing erosion at the present time.

R. W. Fairbridge and C. Teichert - Describe Biological, Mechanical and Chemical Formation Processes.

During this post-war period, R. W. Fairbridge and C. Teichert investigated calcareous coastlines on islands off Western Australia. One of their major objectives was to trace Quaternary sea-level changes through the examination of coastal features including benches cut in lagoon limestones. The two authors usually worked independently but agreed in their interpretations of the features they observed. An article representative of their work was published by R. W. Fairbridge in 1948 under the title "Notes on the geomorphology of the Pelsart Group of the Houtman's Abrolhos Islands".

Fairbridge favored three mechanisms for bench formation in limestone: biological, mechanical and chemical. He considered chemical action to be the most important in bench cutting, with other factors locally significant. He supported Emery's conclusions relating to pH changes due to biological activity and added a theory of similar pH change resulting from temperature variations in surface water.

Fairbridge reasoned that a rise in temperature on the reef flat from 19° C. to 27° C., such as he had observed, would cause a reduction in CO_2 solubility and a rise in pH. This condition would cause calcium carbonate to come out of solution and be precipitated as a fine white powder, again a situation which he had noted. He believed that in the evening a reverse process would take place due to cooling of the water and more CO_2 would be taken into solution with an attendant drop in pH. Solution could then take place on the clean surfaces of limestone which had been cleared of precipitate by wave action.

Biological erosive factors were considered to be the boring, burrowing and dissolving action accomplished by various types of animals and plants. Polychaete worms; boring pelecypods; nibbling gastopods, echinoids and fish; and gastropods capable of chemically dissolving rock were all listed as important agents. Fairbridge felt that the combined action of all these organisms could loosen and expose the outer six to twelve inches of the reef surface to greatly facilitate chemical and mechanical erosion.

Fairbridge stated that mechanical erosion was accomplished by the swash of debris across the bench and had a pronounced polishing action which was most effective at mean sea level. Because he believed that chemical erosion was also most effective at mean sea level, he interpreted any pronounced bench which was not presently at this height as an indication of eustatic change.

Fairbridge and Teichert recognized three former high levels of the sea at ten to eleven feet, five to six feet and two to three feet above the present datum of low spring tides. Other levels were mentioned, but with less assurance. Many workers disagreed with the conclusions drawn by Fairbridge in this and later papers. Unfortunately, in criticizing his opinions on sea level change some have overlooked the value of Fairbridge's observations concerning the processes involved in marine erosion.

DOMINATION BY THE "MELBOURNE SCHOOL" - 1949 to 1951

E. S. Hills - Reviews Shore Platform Theories and Suggests Replacement of the Term "Water-Level Weathering" by "Water-Layer Weathering".

From 1949 to 1951 Hills, Jutson and Edwards wrote prolifically about shore platforms. It was an unusual occurrence to have three shore platform workers residing in the same city, and it may have been this close contact which prompted the flow of papers. After a break of nine years since the publication of his previous article on the subject, Hills submitted a paper entitled "Shore Platforms" to the Geological Magazine in 1949. The paper was largely a review of shore platform study, although Hills did introduce some original material.

Hills proposed several terminology reforms in this article. He wrote that the terms "normal" and "abnormal" when applied to shore platforms were confusing and should be discontinued. Bartrum had originally coined the names in 1926 when referring to the "normal" profile of equilibrium described by Fenneman and the "abnormal" disruptions of this smooth profile caused by shore platform development. Jutson had later confused the issue by naming his high level platform the "normal platform". Hills felt that the term "normal platform" should be dropped and "abnormal platform" used only when circumstances in platform formation were unusual.

Wentworth's "water-level weathering" also came under Hills' attack. Hills agreed with the process, but was unhappy about the possibility of confusion through misinterpretation of the name to mean a mechanism operating only at sea level. As Hills pointed out, D. W. Johnson had criticised Wentworth on this basis soon after the term appeared in 1938. Johnson had seemingly left it to Wentworth to change the name if he saw fit, but Wentworth failed to make any revision in later papers. Now, in 1949, Hills suggested that the name be changed to "water-layer weathering" for the sake of clarity.

After disposing of the terminology argument, Hills discussed factors pertinent to the development of shore platforms. He considered the importance of water-layer weathering, the growth of marine organisms, and wave attack in this context. Water-layer weathering, according to Hills, was a very important mechanism, but was limited to rocks which fretted more rapidly under conditions of alternate wetting and drying than when permanently saturated. Agreeing with Wentworth, Hills stated that ramparts rose above the general level of the platform at the seaward edge and resulted from constant water saturation. He surmised that the rampart would be retained while the platform remained above the level of saturation, but would disappear when the platform was lowered to that level. Organisms, Hills continued, acted both to protect the platform from abrasion and to hold the rock in a saturated condition by inhibiting drying.

On the subject of wave attack, Hills wrote that it was probably less important than sub-aerial weathering in eroding sea cliffs. He described wave attack as a process which ideally results in a submarine shelf below water level, sloping continuously to a wave ramp at the shore. If conditions of rock hardness and wave attack are favorable, the slope might be interrupted by a shore platform. Hills observed that platforms were widest on sheltered coasts, and narrower and less regular on open, gale struck coasts.

Hills' paper was a worthwhile attempt to present the current state of development of shore platform study. The most enduring result of the article, however, was the adoption of the term "water-layer weathering" to replace Wentworth's original nomenclature.

J. T. Jutson - Combines Wave Planation with Water-Layer Weathering and Salt Recrystallization.

Even though J. T. Jutson was a Melbourne contemporary of E. S. Hills, he ignored the suggestion to streamline the shore platform terminology. In 1949, Jutson published two articles on shore platforms in the same issue of the Proceedings of the Royal Society of Victoria, in which he used the term "normal" as in previous papers to denote a narrow bench exposed at low tide.

The first paper contains Jutson's description of the shore platforms of Lorne, Victoria. These features are cut into strongly jointed Jurassic sediments with varying angles of dip. The "normal" platform was delineated as an upper, smooth surfaced platform ("high-level platform") and a lower platform ("low-level platform") itself having three divisions. The low-level platform, Jutson stated, was divided parallel to the coast into an abrasion ramp, a depression, and a rampart. He attributed the formation of both the high level and low level platforms to the direct planing of waves combined with water-layer levelling and salt recrystallization.

Jutson observed that both platforms were being extended landward at the present time while the seaward margins were being destroyed by marine erosion. He suggested that the low-level platform was originally at the height of the high-level platform, but that it had since developed its three division morphology. Shelves and terraces above the normal platform also indicated fresh erosion to Jutson and he concluded that "There is no evidence known to the writer that both platforms have not been formed with sea-level as at present."

J. T. Jutson - Favors Contemporary Wave Planation.

The second 1949 article, "The shore platforms of Point Lonsdale, Victoria", contains a report on fairly large features cut in variously dipping dune limestone. Jutson found none of the ramparts present in the previously described platforms, but did note an abrasion ramp. He characterized the platforms as supporting numerous irregularly shaped rock holes which were attributed to solution. This evidence for solutional formation notwithstanding, Jutson favored wave planation as the developmental process for a number of reasons. Firstly, he stated that the platforms couldn't be explained in terms of "Old Hat" formation, although he failed to give his reasons for the conclusion. Next, Jutson said that solution was very important in the formation of rock holes and irregularities, but could not form the original platform. Insufficient periods of dryness due to the platform's location below high tide level, combined with no evidence for salt crystallization disintegration prompted Jutson to eliminate water-layer weathering as a platform producer. Finally, with the statement that cliffs are presently being undermined by waves, Jutson concludes his argument for contemporary wave planation.

J. T. Jutson - Discusses Wave Planation and "Sapping".

Jutson continued his literary contributions in 1950 with two more articles in the Proceedings of the Royal Society of Victoria. The first paper is a description of the "Shore platforms of Flinders, Victoria, Australia" while the second is a far more general (and useful) attempt to systematize shore platform terminology.

The shore platforms of Flinders, Victoria, are described by Jutson within his usual three level classification: high level, normal and ultimate. Normal platforms were found to be wider in the bays than on exposed coasts and reached a remarkable width of 1,122 feet in one sheltered location. The structure of the rocks, slightly undulating bands of Cainozoic basic lava flows, tuffs and agglomerates, probably is at least partly responsible for the wide platforms noted.

As in previous publications, Jutson attributed the normal platform to wave planation with subsequent lowering by water-layer levelling and a process the author called "sapping". Sapping was defined as a process resulting from the retreat of the tide, leaving behind wet areas which become softened and break off. Jutson considered the role which scour might play in platform lowering, but decided that it was not great because of the many pools which supported vegetative mats. Although he had mentioned the presence of pools, Jutson claimed that the absence of ramparts eliminated Wentworth's pool weathering as a factor. He did credit wetting and drying with being a big factor in rock disintegration and suggested that rain may also help in this respect. No crystallization of salts was noticed on the platform to assist in the general breakdown of the surface.

As Jutson had observed, the general result of the processes described above would be a roughening and lowering of the platforms. Jutson had also repeated the comment that the normal platform was carved originally by wave planation with sea level as at present. What he failed to explain was why a high platform which was formed by wave planation with present sea level conditions should in all of the cases described, suddenly cease to show signs of effective abrasion and be roughened by a sub-aerial process.

J. T. Jutson - Proposes New Terminology and Platform Classification System.

Jutson's most important contribution to the shore platform literature was his 1950 paper "On the terminology and classification of shore platforms". In this article, Jutson presented a new terminology and classification of various forms of shore platforms to replace the existing terminology which he considered incorrect and inadequate.

Briefly, Jutson's classification was as follows:

I. Major platform (Fenneman's profile of equilibrium)

   A. Primary platform - no minor platform between shore and major platform.

   B. Secondary platform - follows minor platform upon retreat of seaward edge.

II. Minor platform.

   A. "Old Hat" type - sub-aerial erosion, marine transport.

   B. Wave erosion type - storm wave platforms.

      1. May be multiple levels.

      2. May or may not show structural control.

   C. Spray erosion type.

      1. Located to heights of 100 feet above sea level.

      2. Usually expressed by erosion of less resistant material.

   D. Water levelling type - as described by Wentworth.

   E. Solution type - as described by Wentworth.

III. Raised and sunken platforms - to be dealt with as needed by use of qualifying terms.

Although this system of classification went largely unheeded or unnoticed by the majority of workers outside Australia, it did attempt to perform a very necessary function. Lack of standardized terminology caused, and still causes, confusion and misunderstanding among students of shore platforms. However, it is difficult to build up a cogent classification system on the basis of supposed formational processes. In this respect, a disadvantage of the Jutson system was that it pre-supposed storm wave origin for one type of platform; the correctness of this line of reasoning is still not established. The chief value of this classification attempt was not so much in the new terminology proposed as in the simple cataloging of shore platform types and processes. Too many articles appearing in the literature seem to be presented without a firm knowledge of the mechanisms and forms which have already been described. However, a summary such as this of Jutson's, though difficult to organize, serves to improve communication throughout the field.

A. B. Edwards - Defends Storm Waves as Platform Producers.

In the next year, 1951, A. B. Edwards again called attention to the platforms of Victoria. The paper bore the title "Wave action in shore platform formation" under which it appeared in the Geological Magazine. Edwards' chief concern in the article was the defence of storm waves as platform producers, in answer to Hills' 1949 remarks as to their unimportance.

Hills had prompted this reply by suggesting on page 149 that wave action could not initiate platforms because "the formation of such a platform would require maximum erosion at a defined level, which is not expectable with variation in wave height, also because the seaward edge of the platform would surely be more eroded than the landward, and again, because even in a tide-less sea, with waves of constant height, the dissipation of energy in waves of translation requires that they form a ramp sloping seaward".

The defence was based on Edwards' opinion that a definite level could, and does, result from the infrequent pounding of storm waves. He cited evidence for the efficiency of this pounding in the occurrence of kelp holdfasts found on shore after storms. 90% of the holdfasts were gripping pieces of stone weighing up to twenty pounds. Edwards failed to point out, however, that this plucking must have taken place in the offshore zone and not on the "storm wave platform" itself. There was also no mention of the actual mechanism acting to allow storm waves to cut a high level platform instead of a lower abrasion ramp, other than the statement that wave attack during storms "is predominantly at a level so raised that it brings the brunt of the attack against the main cliffs". Elsewhere in the article Edwards mentions the protection from weathering afforded by saturation in basalt cliffs but no connection is made with the level to which storm wave platforms would be cut.

Edwards stated further that if the process of water-layer levelling were the cutting mechanism, as postulated by Hills, then ramparts would be always present and rejuvenation of ramparts would be impossible. Edwards claimed to have seen many platforms without ramparts and some features which he interpreted as rejuvenated.

While Edwards maintained that vigorous high level erosion initiated and maintained the platforms, he was willing to give other processes some recognition as agents of planation and lowering. Planation came about, in his view, as a result of the scouring action of waves of translation armed with sand and pebbles. Edwards felt that water-layer weathering was also important in platform lowering and "in favourable circumstances can become the dominant process in further levelling and lowering of platforms."

Like others who have tried to explain shore platforms in terms of storm wave formation, Edwards did not answer the basic question of why, if storm waves have the energy to cut higher up on the cliff, they do not at the same time cut deeper into underlying rock, including the seaward edge of the platform.

THE STEPPED PROFILE - 1952

R. W. Fairbridge - Refutes Johnson's Theory of Erosion to a Deep Wave Base and Points out the Widespread Occurrence of a Stepped Profile.

In 1952, R. W. Fairbridge presented a paper entitled "Marine Erosion" to the Seventh Pacific Science Conference. The main theme of the article was the refutation of the Fenneman-Johnson concept of erosion to a deep wave base. Fairbridge believed that English and American workers in particular were prone to "exaggerate the forces of mechanical marine erosion and ignore the processes of sub-aerial and chemical decay in the formation of coastal benches or terraces."

Fairbridge noted that sonic sounding measurements which were then becoming widely available showed that the most usual profile off stable coasts was not a "profile of equilibrium" but a series of steps, either sloping gently outwards or even "more or less horizontal". He felt that this was the case for the reason that "major changes in sea level, ranging through the Tertiary and Pleistocene, right up till today, have kept the profile in a continuous state of alternate rejuvenation and drowning" which allowed insufficient time for efficient abrasion to wave base.

On a more local scale, Fairbridge had noticed that most "wave cut" shore platforms had a steep outer edge which did not merge gently with a sloping profile. He went on to say that a shore platform would be a normal development on a stable coast and that the longer the sea level remained constant, the wider would be the platform. The platform would then grow until the sea could not continue to wash away debris and platform development would be choked off.

Fairbridge, as in previous papers, credited sub-aerial weathering, chemical activity, and abrasion as the chief platform producers. He stated: "Sub-aerial erosion operates rapidly and deeply on many rock types, but is arrested in depth by sea-level, for alkaline sea-water acts as a preservative for most rock materials, in contrast to the destructive character of acidic rainwater. Thus, below the inter-tidal belt, the erosive action of the sea is negligible in contrast to that of the atmosphere; the critical zone of erosion is in the inter-tidal levels, where rock materials, loosened and partially disintegrated by sub-aerial forces, are etched, abraded, quarried, and washed away by the surf". (Page 349). He then repeated his earlier observations on CO_2 variations in aereated sea water which might make solution possible. Fairbridge emphasized that these factors would be important on both calcareous and non-calcareous coasts.

Up to this point in the paper, Fairbridge had been on fairly safe ground. Although possibly not all mentioned in the same article before, the various concepts had already been advanced by

Bartrum, Jutson, Edwards, Wentworth and others. Now, however, Fairbridge progressed to more contentious issues. He disagreed specifically with J. A. Bartrum in writing that "the base level of sub-aerial erosion is not high-water but low-water spring tides". Although Fairbridge had stated this opinion previously, this was the first time he had directly challenged Bartrum's "Old Hat" weathering concept. Fairbridge then developed the theory that the "Old Hat" type platform was not a contemporary feature at all, but a relic, indurated at low-tide level during a recent ten foot stand of the sea. He continued in the same vein by explaining the various levels of "storm wave" and other platforms around the Pacific as being the result of this level and other stands at two to three feet and five to six feet.

Once again, Fairbridge's thinking on most of the basic issues involved in shore platform development was sound. When he tried to apply it to the measurement of previous sea-levels, however, he stirred up major disagreement. One difficulty with Fairbridge's argument would seem to be that, if platform developing processes are active enough to form an extensive platform at low tide in the short time that he claims that sea-level has been at the present level, then platforms located at present high tide should be greatly degraded and support little horizontality.

J. A. Bartrum - Criticizes Fairbridge's Concepts.

J. A. Bartrum immediately responded to Fairbridge's attack in the discussion following the presentation of the paper. He later elaborated on these comments in an article which was printed after "Marine Erosion" in the Proceedings. Bartrum counter-attacked by stating on page 358, "Dr. Fairbridge's observations of shore platforms in rocks other than limestones, which have abnormal solubility compared with most other rocks, appear to be limited. On New Zealand shores there are hosts of examples of wide, gently-sloping subaqueous platforms which have the profile demanded by Fenneman, Gulliver and others of their school. He also minimizes the corrosive potentialities of waves as compared with sub-aerial processes, but any observer can readily satisfy himself that, in normal rocks, given suitable tools, waves are extremely capable corrosive agents".

Bartrum strongly disagreed with Fairbridge's placement of the base level of sub-aerial erosion at a level of low water spring tides. This would be possible, Bartrum stated, for permeable rocks or those having closely spaced, open joints, but such a platform would be quickly eroded by corrosive wave action into a "normal" profile of equilibrium. He added that platforms of the "Old Hat" type were produced with conditions as at present at an elevation representing the saturation level in rocks - a foot or so below high-water level.

Fairbridge's explanation for "storm wave" platforms also seemed unlikely to Bartrum. He felt that there was good evidence to show that these platforms, with their surfaces from a foot or two to eight feet above high-water level, were products of the sea at its present level. Bartrum said that the platforms are developed only in fairly resistant rocks free from open joints at exposed locations where offshore reefs cause storm waves to sweep in as waves of translation. Reasons listed for present development were: (Page 359)

(1) One can observe waves thundering on to these platforms during storms.

(2) The benches never pass far from the end of a headland towards a bayhead.

(3) When they do so, they decline in level away from the headland. Occasionally the change to a lower platform is abrupt. In these cases observation shows that the waves responsible for carving the platforms have had their vigour reduced after passing the headland; at times this reduction is because of deflection.

Bartrum added that the platforms were unlikely in open-jointed rocks, which would be disrupted at varied levels by pneumatic and hydraulic pressures.

In concluding, Bartrum wrote, "I would claim that Dr. Fairbridge has advanced no cogent reason for regarding platforms of the 'Old Hat' and 'Storm-wave' type as developed during a period when sea-level was higher than now. They therefore have no value in isotatic correlation of shore benches". (Page 359).

J. A. Bartrum's defense of his position against the remarks of Fairbridge constituted his last article on shore platforms. In the years from 1916 to 1952 he had published eight papers pertaining to the development of shore platforms in both exposed and sheltered locations. Although some have argued with Bartrum's conclusions, the impetus which Bartrum gave to the development of knowledge about shore platforms was considerable.

PROCESSES OF EROSION - 1954 to Present.

J. T. Jutson - Lists Processes of Erosion.

As the study of shore platforms progressed, workers in the subject became increasingly aware of the complexities inherent in platform development. Geomorphologists could now list a number of formational factors, but specialists were required to fully explain the processes. These detailed investigations gained momentum in the 1950's and continue to the present time.

In 1954, J. T. Jutson gave his summation of the platform producing mechanisms in a paper entitled, "The shore platforms of Lorne, Victoria, and the processes of erosion operating thereon". The shore platforms themselves were "minor platforms" with ramparts, depressions and abrasion ramps, cut in feldspathic sandstones, mudstones and shales. More complex were the processes of erosion, which included quarrying, planing, grooving, flaking, pitting (honeycomb weathering), minute furrowing, saucering and water-layer weathering.

Jutson had put considerable thought into his list of processes and described each mechanism in detail. Wave quarrying, the first on the list, was said to be effective on the rampart and along channels cut into the platform. The next process, planing, acted both horizontally and vertically yielding smooth rock surfaces through sand rasping. Grooving was described as a related mechanism producing features several inches wide and deep along joint and stratification planes, with particular prevalence on the rampart. Erosion taking place along the stratification planes may also, according to Jutson, result in flaking on ramps and depressions with dips less than a few degrees. Pitting is yet another process which weakens the rock to allow subsequent erosion and removal by wave action. In Jutson's view, pitting (and honeycomb weathering) occurred through alternate wetting and drying, chemical decomposition and possibly the crystallization of salts, all taking place in the zone affected by wave splash.

Jutson continued his discussion of the erosion processes with the mention of minute furrowing. This feature resulted from a combination of sand scour and flaking due to wetting and drying which produced grooves about 1/8" to 1/4" deep and up to one inch wide. Jutson cites these furrows as evidence to show that a practically horizontal surface may be caused and maintained by the planing action of the sea. Saucering also was a part of this planing action, according to Jutson. Saucers occur when the iron oxide deposits in joints are more resistant to chemical action than the rest of the rock surface. The features are most prominent on the rampart and may become several inches deep on a number of different levels.

Jutson banished water-layer levelling to the fringes of his hierarchy of processes. He claimed that water-layer levelling would only be effective after platforms had been cut by wave planation and sub-aerial erosion and even then would be important solely on parts of the depression and small flat areas of the rampart.

All of Jutson's processes probably are present in greater or lesser degree on shore platforms. The relative importance of the different mechanisms is debatable, however, and water-layer weathering should receive more attention than Jutson chose to give it. A major omission from Jutson's collection of processes was the biological factor. Jutson, in common with many other mid-latitude geologists, evaluated shore platforms in terms of the field in which he was most acquainted, extracting only geologic information from the complex matrix provided by nature. Only recently has the student of non-tropical shore platforms shown an appreciation of the tremendous influence builogical activity can have in platform genesis.

W. J. North - Measures Erosive Activities of Snails.

W. J. North, a marine biologist working at the Scripps Institute of Oceanography, emphasized the importance of biological factors in a 1954 publication. The paper dealt specifically with the marine intertidal snails, Littorina planaxis and Littorina scutulata, common on the California coast. North noted the size distribution, gross metabolic efficiency, and erosive activities of these snails through a combination of field observations and controlled experiments.

In discussing the erosive activities, North on page 190 explained: "The snails feed by applying a file-like ribbon, the radula, to the substratum and transfer bits of it to the mouth by a scraping action". North continued that, "On the cliffs around La Jolla (composed of Cretaceous sandstone) the animals scrape algae and fine detritus from the rocks and at the same time remove particles of the rock itself".

North embarked upon an extensive laboratory study to quantify his observations. He extracted snails from their shells, incinerated the bodies, dissolved the body ash in concentrated hydrochloric acid and finally weighed them to determine the amount of sand ingested. He conducted other experiments to determine the time required to renew material in the gut.

The results of the two experiments were combined to determine the rates of erosion. The average amount of inorganic material removed from the gut of a snail of average height (0.8 cm.) was 1.6 mg. Coupling this value with the most conservative cycling period of four times daily, produced a figure of 6.4 mg. of inorganic material derived for each snail per day. The density of the sandstone upon which the snails were grazing was 2.5 g. per cc. so that one hundred 0.8 cm. high snails could excavate an 86 cc. basin yearly - almost a litre per decade. North, through field observation, found that the concentration of L. planaxis is of the order of one snail per 30 cm^2. At this concentration, this species would deepen pools one cm. per forty years. L. scutulata occurs in even greater concentrations, with one snail per 12 cm^2, and assuming similar feeding habits would yield a combined erosion rate for both species of one cm. per sixteen years.

North's figure of one cm. per sixteen years, or one foot per five hundred years, for the amount of erosion accomplished by snails, is of the same order of magnitude as other values determined by different methods. K. O. Emery in 1946 estimated that lowering due to all factors would amount to about one foot per one thousand years. Emery later reported (1960) that wetting and drying, combined with solution of calcareous cement would cause the removal of one foot of material per six hundred years. In addition, E. P. Hodgkin (1964) measured erosion in limestone of about one mm. per year over a ten year period, or a rate of about one foot per three hundred years.

This recognition of biological factors, accompanied by attempts at quantification, marked the start of a new period in shore platform study. Description had served workers for over one hundred years, but the need had become increasingly great for detailed study of erosion mechanisms to explain the formation of platforms. North's paper joined K. O. Emery's 1946 publication in marking a turning point in the development of shore platform research.

<u>K. O. Emery and H. L. Foster - Note Sub-aerial Weathering in Coastal Tuff</u>.

Two years after North's publication, K. O. Emery examined another facet of the problem of platform growth. Emery joined H. L. Foster in 1956 to produce a paper entitled: "Shoreline nips in tuff at Matsushima, Japan". The two authors found well developed intertidal nips in the tuffs of Matsuchima and explained the features in terms of partial weathering followed by the removal of the loose grains by erosional agents.

Emery and Foster considered wave erosion as the sole cause of the nips, but rejected the hypothesis on several grounds. Firstly, the nips are backed by softened and frequently scaly tuff covered in part by attached plants and animals, which would seem to indicate that waves are not actively cutting into bed rock. In addition, the intricate shoreline and abundant islands of the region afford shelter from large waves. Finally, the nips are more fully developed on the sheltered, landward portions of the islands than on the seaward coasts.

The authors found weathering, combined with wave transport, to be a more promising mechanism in the production of the nips. They stated that weathering might be accomplished by solution and hydration promoted by frequent wetting and drying. The two workers also felt that organic acids liberated by attached organisms could aid the weathering process. Once weathering had loosened the grains of tuff, the particles may be dislodged by waves, currents, wind or even the activities of animals.

Emery and Foster described an interesting occurrence of local case hardening in the tuffs of Matsushima. They felt that the case hardening resulted from the leaching of the interior of the tuff and that only a minor change in the tuff itself is adequate to produce either a resistant case-hardened surface or a nip.

R. Revelle and K. O. Emery - Study Solution Processes.

K. O. Emery had a number of scientific interests, but found time to publish another article pertaining to shore platform formation in 1957. This work, "Chemical erosion of beach rock and exposed reef rock", was co-authored by Roger Revelle, head of the Scripps Institution of Oceanography at La Jolla. The publication was part of a comprehensive U. S. Geological Survey Professional Paper compiled as a geological inventory of the Marshall Islands nuclear test area of the Pacific.

Revelle and Emery again sought to back up description with precise measurements in their work. As stated on page 705, "Geologic evidence suggests that some process of solution is of great importance in removing limestone in the intertidal zone. This process is faster than solution by rain water, as indicated by the existence of intertidal nips in water sheltered from wave action. That it is much faster than solution below the intertidal zone is shown by the fairly level surface of the reef flat at a depth less than thirty cm. below normal low tide". In an attempt to isolate the mechanisms involved, the authors measured temperature, oxygen content and hydrogen-ion concentration in basis and on the reef flats. Water samples were also collected at the same time for subsequent chlorinity determination.

The measurements showed pronounced diurnal changes in the alkalinity-chlorinity ratio of the water in the depressions, which would seem to indicate that a fairly rapid solution of calcium carbonate could occur. However, a difficulty arose when computations based on the experimentally determined solubility product of calcium carbonate in sea water indicated an apparent supersaturation in the basin and reef water of from 175% to 800%. As the authors explained on page 699, "Possible rationalizations of these opposing lines of evidence are that (1) solution may occur within the limestone of the basin floors or in the interstitial water of the algal mats which cover some of the floors; (2) solution may occur in the films of water left on the basin walls by the receding tide; or (3) much of the calcium may be complexed or hydrated, and the time involved in the formation and dissociation of complexes containing calcium is long relative to the time required to precipitate free calcium ions or to obtain them from solution of calcium carbonate".

Revelle and Emery considered that if the calcium were indeed complexed or hydrated solution could occur when the carbonate concentration or temperature, or both, were decreased. Since erosion of calcium carbonate is confined to the intertidal area where pronounced diurnal variations in conditions are common, the authors felt justified in proposing that complexing or hydration could be a major factor. They also suggested, as Emery had done previously, that night time cooling in intertidal basins, coupled with respiration by plants and animals, could favor solution through dropping the temperature and pH and raising the carbon dioxide content of the water.

Emery and his co-authors in the 1956 and 1957 papers had indicated the importance of solution and hydration in two vastly different rock types: limestone and tuff. In earlier works, Emery had studied the same processes on sandstones. As the evidence for this type of weathering in various types of rocks accumulates, the argument for straight wave erosion in the intertidal zone becomes less attractive.

C. A. M. King - Supports Storm Wave Activity as a Major Platform Producing Mechanism.

Storm waves still have some strong supporters, however, as indicated by C. A. M. King in the 1959 publication Beaches and Coasts. King mentioned corrosion, corrasion, attrition and hydraulic action as the four most important platform producers, but heavily favored corrasion and hydraulic action, especially during storms. She made no mention of biological or biochemical processes which might be active, except to quote Edwards' 1951 paper wherein he described kelp holdfasts containing rocks being thrown onto the platform during storms.

King was apparently quite impressed with Edwards' explanation of shore platform formation and spent almost a page in synthesizing his article; the paper in which Edwards attempted to justify storm wave formation in the face of criticism by Hills. Neither Edwards or King could satisfactorily explain why storm waves should erode a horizontal platform rather than a sloping ramp. Once again the change of geographic location seemed to be exerting a large influence on the development of a researcher's thinking. In Britain, rock abrasion during storms is an important factor in coastal erosion. This appears to cause British geomorphologists to place undue emphasis on abrasion when considering processes of coastal erosion in general, worldwide terms.

C. A. Kaye - Discusses Solution by Sea Water.

During this period, the middle to late 1950's, the most important work on shore platforms was being accomplished in tropical limestone areas. Some of the problems were unique to coral and eolianite, but other processes were described which were more widely applicable. The study was being carried on in two main areas; workers such as Emery and his colleagues had been concentrating in the Pacific region while a number of other scientists had been examining limestone shores in the tropical western Atlantic.

One of the researchers working in the Atlantic was Clifford A. Kaye. In 1959, he published a U.S. Geological Survey Professional Paper entitled: "Shoreline Features and Quaternary Shoreline Changes, Puerto Rico". This publication was concerned with a wide variety of subjects and included a well thought out section on shore platforms, nips and solution pits in eolianite.

Kaye, not content with Wentworth's designation "solution bench", renamed the numerous shore platforms of Puerto Rico "tidal terraces". The tidal terraces, according to Kaye, were the result of two distinct solution mechanisms working together. One process involved was the production of the nip and the other was solution pitting. Little evidence was found for direct wave abrasion as a platform cutting agent in this region.

The plentiful nips were attributed by Kaye to solution by unsaturated, surficial sea water. He agreed with other authors that sea water was usually saturated with $CaCO_3$, but postulated that "because of such factors as variation in salinity (resulting from land drainage and from heavy precipitation falling directly into the sea), organic generation of CO_2 in the ocean itself, and temperature changes, surface waters are occasionally undersaturated"; (page 95). Kaye suggested that the nips were thus solutional features, with the reaction enhanced by the agitation caused by wave action. Wave action seemed to be important to the process because Kaye found that the upper level of the nip corresponded to the mean wave crest level, while the lower limit of the nip was at the altitude of the wave troughs. Kaye concluded that the tidal terrace produced by the recession of the nip was not dissolved itself because of a protecting growth of coralline algae.

Kaye had an opportunity to determine the rate of formation of sea-level nips through historical evidence in Puerto Rico. Spanish engineers blasted large boulders from the eolianite shore in 1797 to block a channel under attack by the English navy. Some of the boulders came to rest on a pitted tidal terrace where they have been exposed to the ocean on one side and a lagoon on the other. Kaye related that "A well-defined though relatively shallow nip girdles the base of one of the boulders. On the ocean side the nip measures 4" at its maximum depth while on the lagoonal side it is 10" deep at the deepest point". These figures would give erosion rates of one foot per five hundred years in the exposed location and one foot per two hundred years on the more sheltered side.

Solution pits were another common feature of the Puerto Rican limestones. Kaye proposed that the pits were caused by fresh water solution and had characteristic shapes depending on location. Above the spray zone the pits resulted from rain water activity and typically had rounded bottoms. The pits in the spray zone, however, were quite different. Here, Kaye stated, the pits had much flatter bottoms and undercut rims, reflecting some horizontal dissolving mechanism. Kaye theorized that rain water floating on sea water in the splash zone could account for the observed conditions. He generally agreed with Emery's ideas on solution in tidal pools, but didn't think that such biochemical reactions were essential in explaining the Puerto Rican features. The occasional solution by fresh water could gradually lower the pit until it reached a level where sea water had sufficiently continuous access to inhibit the process.

Yet another process may be active in pitting which is purely mechanical in nature, continued Kaye. Salt crystallization, that process which is so difficult to evaluate, was considered to be of importance in "pool level erosion". Kaye explained that "as a spray pool evaporates and the level falls, it leaves behind a thin collar of salt on the pit walls. The crystallization of the salt in the fine pores of the eolianite most certainly dislodges the tenuously cemented sand grains of the eolianite".

Like most workers in the tropical limestone areas, Kaye gave great importance to the biological factors acting on the shoreline. He felt that *Lithothamnium* encrustations were important in protecting the tidal terrace from solution, as mentioned previously. In addition, serpulid tubes and dense colonies of mussels were sometimes found to function as protective cover on the platforms. On the destructional side, Kaye cited the erosive effects of the periwinkles, echinoids, holothurians and chitons. Periwinkles were considered to be important agents in removing sand grains from the bottoms of solution pits, while the other organisms were credited with producing quite significant pits by themselves.

K. O. Emery - Summarizes Developmental Factors and Emphasizes Biological Activity.

In 1960, K. O. Emery combined his studies of both temperate and tropical areas in his book, "The Sea off Southern California". The book is a well organized regional treatment of many aspects of the widely varied Southern California oceanography. Because this area is so diverse, Emery is able to discuss many of the topics studied elsewhere in the world.

Emery sums up his thoughts on shore platforms in an eleven-page section of the book headed, "Erosional Coasts". He stated that the powerful forces of abrasion and hydraulic plucking were definitely important in coastal erosion, but that some other agencies were more difficult to evaluate in terms of effectiveness. For example, Emery questioned the efficiency of the compression and expansion of air trapped in caves or joints by waves and cited some very spectacular spouting horns which have lasted for decades in various parts of the world. Another, less violent form of erosion that Emery mentioned was the expansion of scales and the loosening of grains by salt crystal growth. He was dubious about the importance of this process and stated that neither field nor laboratory tests seemed to support the hypothesis.

In contrast, Emery was very impressed with the value of some other erosive processes. Wetting and drying of rock in and near the intertidal zone was mentioned as being quite a significant form of erosion, particularly in the many sedimentary cliffs of Southern California. Emery related that dissolving of cement might be a factor in this type of erosion, but that base exchange, hydration, or the loosening of the grains through swelling were probably more important. He reiterated his 1941 findings of a rate of surface wastage amounting to one foot per six hundred years for sandstones at La Jolla as the result of wetting and drying.

Emery also favored biological activity in the intertidal zone as a "much overlooked means of erosion". He stated that biological activity could affect intertidal rocks by either mechanical or chemical processes. Borings by worms, pholads, chitons, limpets and sea urchins contribute greatly in erosion, while snails also remove material by grazing on the rock surface. Emery explained that most of these animals ground or rasped indentations in the rock, but that some were capable of dissolving holes for protection.

Another facet of biological erosion was the interaction with the chemistry of intertidal sea water resulting in biochemical activity. As Emery had stressed in his 1946 paper on solution basins, this phenomenon is an effective agent of erosion in a wide variety of rocks including limestone, sandstone and even basalt. The process itself involves changes in temperature, salinity and pH brought about by diurnal variations affecting plants and animals in the pools. Solution is favored at night, according to Emery, when CO_2 liberated by animals is not consumed by photosynthesis and the alkalinity of the pool water increases considerably. Emery estimated that the rate of deepening of solution basins in Cretaceous sandstones at La Jolla, California, is about one foot per one thousand years.

Emery ended his section on shore platforms with a discussion of the origins of the low rock platforms which occur in Southern California and elsewhere in the world. These platforms were described as being located near the high tide level and bevelling dipping beds of basalt, sandstone, breccia and siliceous shale. Emery related the platforms to the features reported by Bartrum, Jutson and others which they attributed to storm wave action.

The storm wave formation theory failed to capture Emery's loyalty for several reasons. He felt, in the first place, that Bartrum's platforms may have been formed by earth movements (although Bartrum himself had considered and rejected this possibility for the platforms he mentioned). "Moreover", Emery stated, "it is difficult to see why storm waves, being larger than ordinary ones, should not erode deeper rather than shallower than usual. Certainly all storms do not have waves of the same height, nor do they occur at tides of the same height, so at best we would expect storm terraces to have profiles with outer edges that are convex upward. However, most low rock platforms in southern California and elsewhere have abrupt outer edges". Emery also pointed out that the occurrence of platforms at the same level on both the exposed and sheltered sides of Californian offshore islands would suggest that terraces were not of storm wave origin. Yet another argument against storm wave formation was Emery's observation that many of the sea cliffs of Southern California had large and well vegetated talus slopes at their bases. Emery maintained that the "storm terraces" were formed at a recent higher sea level and are now being lowered by solution basins, water-level weathering and biological processes. He favored a hypothesis of a six foot drop in sea level about three thousand years ago. To justify this view he mentioned tropical raised and dissected reefs and nips commonly present about six feet above present sea level. Although Emery failed to mention the point directly, he seemed to imply that "storm terraces" were originally cut by wave abrasion before the drop in sea level.

PACIFIC ISLAND TERRACE SYMPOSIUM - 1961

H. T. Stearns - Describes Pacific Platforms.

In 1961, the year following the publication of Emery's book, the Tenth Pacific Science Congress was held in Honolulu, Hawaii. A symposium, "Pacific Island Terraces: Eustatic?" was organized by Richard J. Russell and the presentations published in a special issue of Zeitschrift für Geomorphologie. Contributors to the symposium were H. T. Stearns, K. O. Emery, F. P. Sheppard, H. A. Powers, W. G. McIntire, S. P. Chatterjee, F. H. Bauer, E. D. Gill, J. N. Jennings, T. Nakano and N. D. Newell. Not all of these workers were concerned with shore platforms, however, and only some will be reviewed here.

The symposium was introduced by H. T. Stearns, whom Russell called the "dean of Hawaiian geology". Stearns began by explaining the causes of eustatic changes and elaborating on the difficulties experienced in correlating shorelines throughout the world. He then described some ancient Hawaiian shorelines in detail, relating them when possible to features in other locations.

Three pronounced shore platforms are presently visible in or near the intertidal region, according to Stearns. He first described a well developed platform exposed at low tide which bevels across both volcanics and limestones. This platform is termed "the present shore platform", but Stearns did not venture an opinion as to processes involved in its formation. Another platform was named "the two-foot shore line". Stearns stated that it surrounded "most islands in the Central Pacific, especially those with fringing reefs or with tuffaceous rocks at sea level and is always awash at high tide. It has been commonly described as due to work of the present sea, but abundant evidence is accumulating that the ocean is bevelling down an older bench". He proposed that this older bench was formed (in an unspecified manner) from the five-foot sea and had been subsequently eroded to form the two-foot shore line. Stearns cited this as evidence for a "two-foot sea" as he apparently believed that the sea, in some manner not mentioned, eroded these platforms precisely at mean sea level.

The third feature reported by Stearns which could be classified as a shore platform was the "five-foot shore line". This designation was a little imprecise as Stearns had actually measured notches in limestone cliffs on Guam to be exactly 5.2 feet above present mean sea level. Stearns claimed that this shore line is "even better preserved around the islands of the Pacific than the two-foot stand because it lasted long enough to either bevel older reefs, grow new reefs, or cut deep notches in limestone cliffs".

Numerous authors have verified that the shorelines mentioned by Stearns do exist, but interpretations as to their meaning have been varied. As other workers have done before him, Stearns assigned values for previous sea levels on the basis of shore platforms without fully exploring the formative processes.

Symposium Speakers - Discuss Various Aspects of Shore Platforms.

K. O. Emery was the next speaker at the symposium with a paper concerning submerged marine terraces. Following Emery was F. P. Sheppard who presented information on "Sea Level Rise during the

Past 20,000 Years". Briefly, Sheppard related the results of C_{14} dates on organisms and plants that lived close to sea level in relatively stable areas around the world. The data indicated that sea level has been rising at a decreasing rate for the past 20,000 years and is now at its highest Holocene level.

After Emery and Sheppard came H. A. Powers of the U.S. Geological Survey who reported on "The emerged shoreline at 2-3 meters in the Aleutian Islands". Powers described a tundra covered platform about 2-3 meters above sea level at the back of a ten meter wide platform at low tide level. According to Powers, the rocks are bedded sediments of marine origin, interbedded volcanic tuffs and lava of marine extrusion. He went on to tell how the 2-3 meter platform was found on islands in a chain 1,200 miles long which would seem to indicate eustatic change rather than tectonic movement. Powers concluded by saying, "The shoreline features of the Aleutian Islands are compatible with, but do not demonstrate the validity of, the hypothesis of eustatic lowering of sea level from 2 to 3 meters since the time of latest glaciation but prior to 5,000 years ago".

Wm. G. McIntire then presented a paper entitled: "Mauritius: River-Mouth Terraces and Present Eustatic Sea Stand". McIntire mentioned shore platforms very briefly in his presentation and considered the Mauritius features to be the result of storm waves acting upon horizontal, contrasting igneous flows. The platforms he described were from two to eight feet above mean spring low tides with a capping flow of highly weathered doleritic basalt overlying better indurated lava. As was shown in a later paper (McIntire, 1964), storm waves probably are significant platform producers in this area. However, McIntire failed to realise that other processes were also at work even though he spoke of a small island near the Mauritius coast which is entirely surrounded by a "wave-cut platform".

E. D. Gill of Melbourne made only limited reference to shore platforms as did J. N. Jennings who followed. Gill cautioned workers to take care in interpreting previous sea levels by measuring from an elevated shore platform to a lower one. He claimed that an error might be introduced because a change in tidal range alone would affect the elevation of the platform with an increase in range resulting in a lower platform. Jennings, writing on sea level changes in King Island, in Bass Strait, mentioned that the "emerged" shore platforms he studied could have been formed by storm waves at a higher relative sea level or be the result of a reduction of storminess with sea level as at present.

N. D. Newell - Stresses Need for More Knowledge of Processes Involved in Marine Planation.

The final participant in the 1961 Symposium was N. D. Newell, an active worker in the tropical limestone areas of both the Pacific and western Atlantic. Newell's paper, entitled "Recent Terraces of Tropical Limestone Shores", was an elaboration of a note appearing in Science the year before. Unlike many authors, past and present, Newell emphasized that in order to evaluate marine terraces properly "it is essential to have general knowledge of the modes by which marine planation takes place".

Newell felt that several levels of terraces might originate simultaneously at a single locality. An abrasion platform formed by the wearing action of broken corals and shells is a common feature in both the Atlantic and Pacific, according to the author. At a higher level, Newell continued, "a narrow and discontinuous tidal terrace is forming in the Atlantic region near sea level at about the limit of low tides". He explained that this terrace is formed by the interaction of numerous chemical, mechanical and biological activities as had been previously suggested by Emery, Kaye and others.

The importance of biological activities should not be overlooked, cautioned Newell. He stated that "the tendency of many investigators to minimize or to ignore biological agencies of tidal erosion of limestone shores is not warranted by the facts". Newell went on to say, "The capillary fringe of intertidal limestones is riddled by the microscopic perforations of filamentous algae. Other organisms penetrate into the rocks to depths of several centimeters. This is not a local phenomenon; it is universal in all of the seas of the world. In many places I have estimated that the amount of rock substance commonly removed by organisms in the outer one or two centimeters of rock is equal to 50% or more of the volume of the rock, and the perforating activity of organisms tends to be greatest at the axis of the nip".

Newell concluded his presentation with a brief discussion of the "two-meter" terrace of the Pacific and other high islands. He rejected the possibility that the features were cut by storm waves and tsunamis after sea level reached its present level and before protecting reefs were fully established. Newell felt that the ancient, weathered appearance of the low terrace of Tahiti suggested that "much of the terrace-cutting occurred during one of the high still stands of the sea, during the Pleistocene".

THE PRESENT POSITION

C. A. Cotton - Recognizes Requirement for More Information About Formational Processes.

In the 1960's, over one hundred years since Dana's first descriptions, workers were still lamenting the insufficiency of information about the actual platform development processes. Most present researchers, some outside the fields of geomorphology, are attempting to fill in the details of those mechanisms.

C. A. Cotton was one of those who recognized the need for more detailed study into processes. In 1963, Cotton published a brief but useful summary of the shore platform literature under the title "Levels of planation of marine benches". In emphasizing the need for continued study of shore platforms, Cotton quotes E. S. Hills in a lecture to the Geological Society of London, 1st June, 1960. Hills stated, "Unless we understand the ways in which shore platforms are formed it is obviously fruitless to draw conclusions from them about relative movements of land and sea".

Cotton himself still favored storm wave formation as the most likely theory to explain the majority of platforms. He mentioned the impressive string of authors including Bartrum, Edwards and Jutson who also held this view, but did not elaborate on the actual workings of the process.

The possibility of secondary lowering of storm wave platforms was also mentioned in Cotton's review. He was partial to the water-layer weathering explanations of Bartrum and Wentworth and in addition gave some importance to crystallization of salts as a weathering mechanism. Cotton felt that "downwearing by secondary processes explains some reports of the presence of platforms at different levels in adjacent localities". He concluded by stating that, while secondary lowering was probably significant in platform morphology, not all platforms had been modified in that manner.

Cotton seemed to be more impressed with the efficiency of salt crystallization than most other authors had been. In support of his opinion, he cited the work of Jean Tricart on the equatorial coasts of Africa and Brazil. Tricart had published two papers in 1957 and 1959, on platforms in these regions which he attributed entirely to the work of salt crystallization. Tricart argued that the process formed niches and later platforms in areas where insolation was sufficient to cause rapid evaporation of sea water. Although weathering by this process might be slow, according to Tricart, it is still more effective than marine abrasion which is very weak in the hot-humid zone because intense chemical weathering reduces all rocks to fine grained debris unsuitable for scouring. Cotton added that water-layer weathering might be at work to help the salt crystallization process.

The difficulty in the salt crystallization hypothesis, commented Cotton, lay in the production of a level bench from a series of niches. Cotton proposed that the benches may have been produced by storm wave abrasion "at a time when, temporarily, the climate was insufficiently humid to promote that thorough chemical weathering which now inhibits mechanical corrasion. If, as Tricart has suggested, the climate at the 'climatic optimum' was relatively arid, perhaps it was sufficiently so to produce this result". As an alternative, Cotton suggested that the benches may have resulted from an "Old Hat" type removal of weathered material by weak wave action.

Cotton ended his article with a discussion of the validity of determining amounts of emergence from shore platform measurements. He pointed out that "observation of cliff bases in various parts of the world reveals the fact that the landward margin of the "normal" platform cut by marine erosion - or of the lower platform where two cuts are being made into the land - can be at various levels". Cotton recommended that a compromise view be taken in evaluating emergence as he stated, "It would appear that the solution of this problem lies between the positions taken up by extreme eustatists and that of those who believe in the development of high-level platforms with sea level in its present position".

R. J. Russell - Supports Formation of Elevated Benches with Present Sea Levels.

R. J. Russell of Louisiana State University was also concerned with the problem of interpreting the evidence for eustatic change. In 1963, he published a paper entitled "Recent Recession of Tropical Cliffy Coasts" which included the results of a study conducted for the U.S. Office of Naval Research.

Russell held the view that tropical areas, where limestone coasts are common, would provide the best evidence of recent recession of cliffs. He based his reasoning on the statement that "there is some possibility that 10,000 years ago sea level was about one hundred feet lower than it is today. The existing 'stillstand' began about four thousand years ago, and since then fluctuations have been slight, probably within a range of a foot or so". Russell maintained that this time was too short for any appreciable change to take place along coasts of consolidated, durable rock. Only where the exposed formations were poorly consolidated or consisted of limestone, Russell stated, would recession be significant. He added that the traditional concept of "wave-cut terrace - wave-built terrace" would also occur chiefly in limestone or poorly consolidated cliffs, with limited expression elsewhere.

Agreeing with other workers, Russell believed that benches could be formed in elevated locations with present sea levels. He stated, "The retreat of cliffy coasts through abrasion and solutional erosion during recent times has produced a whole complex of forms, including conspicuous benches well above sea level where bed rock conditions are favorable". For this reason, Russell continued, critical examination should be made of claims of higher recent sea levels based on the study of emerged features. Russell concluded that "The case for a higher stand during a recent climatic optimum appears to be poorly founded.....I strongly suspect that many of the anomalous dates for elevated shorelines are dates derived from inadequately cleaned samples".

W. G. McIntire and H. J. Walker - Describe Production of Platform by Wave Stripping During Hurricanes.

Two other Louisiana State University workers, W. G. McIntire and H. J. Walker, combined in 1964 to describe the changes in coastal morphology caused by tropical cyclones on the island of Mauritius. Most of the paper dealt with changes on the non-cliffed coastline, but a short section does mention alterations in the bed rock morphology.

The authors stated that most of the cliffy coasts suffered little change, with the notable exception of a location on the south shore. Here, according to McIntire and Walker, the cliff receded as much as twenty feet as weathered basalt was stripped by wave action from the more homogeneous and durable underlying lava. They considered the resulting bench to be the demarcation between two contrasting lava flows and made no mention of the possibility of saturation control of weathering. The authors finished the subject with a jab, similar to Russell's a~~s~~t those believers in a higher recent sea level: "Features of this kind have been cited commonly but incorrectly as evidence of a higher stand of sea level within recent millenia".

E. P. Hodgkin - Measures Erosion Rates and Favors Biological, Biochemical and Chemical Processes.

One of the final papers to be considered in this review of the evolution of shore platform theory was written by the Western Australian zoologist E. P. Hodgkin in 1964. Entitled "Rate of erosion of intertidal limestone", the article contained observations made by Hodgkin at Norfolk Island off the east coast of Australia and at Point Peron, West Australia.

Limestone steps on a jetty at Norfolk Island attracted Hodgkin's interest when he noticed that the joints in the cut blocks did not match the present surfaces. He ascertained the approximate date when the steps were constructed and measured the amount of erosion to determine the rate. Hodgkin made several conclusions from his observations: "At the lowest level observed, in the upper intertidal, rate of erosion is between 0.6 mm. and 1.0 mm. per year. The rate of erosion decreases with height and decreases frequency of wetting. Erosion is not uniform, presumably due to minor irregularities in the original surface or minor differences in lithology. It is most rapid in depressions where water is retained, as evidenced by excavation of pools several centimeters deep at higher levels, and pools and residual pinnacles at lower levels. Nevertheless, intertidally where the rock is submerged daily, erosion of a vertical surface is little slower than on a horizontal surface".

Results of a measurement program at Point Peron in Western Australia were similar to the Norfolk Island data. Hodgkin made the Point Peron measurements by noting the lowering of the limestone surface in relation to stainless steel pegs which he had installed in August, 1953. Plaster casts made of the surfaces over the years revealed a rate of 1.0 mm. per year at a location just above mean sea level, with lesser rates at higher elevations.

Hodgkin favored chemical and biochemical activity over abrasion as the most active processes presently eroding the limestone. Being a zoologist, he mentioned the importance of the numerous browsing organisms which he found on the rock surfaces, but he felt nevertheless that chemical corrosion was probably an even more significant factor in limestone removal. Abrasion was not considered by Hodgkin to be a very powerful agent on the present benches. He did feel, however, that abrasion might have been important at some earlier date when sea level was a few feet higher than at present.

If an abrasion platform had been created with sea level a little higher, Hodgkin concluded, it could presently be undergoing lowering by pitting and notching. He added that the lowering rate by pitting approximately equalled the undercutting rate by notching and the two together could account for the extensive platforms common today.

Hodgkin, with his zoological and quantitative approach, points the direction which future workers in the shore platform field will take. A greater awareness of the interaction between bedrock and biota is absolutely necessary to the serious study of shore platforms. In addition, more concrete facts are needed about the characteristics of these features. Shore platforms have been studied for over one hundred years, but even basic, simple erosion rate measurements were not made until recently and practically no information has been gathered on exact levels of platforms above sea-level datum.

E. C. F. Bird - Summarizes the Present Position.

The final entry in this literature review is a contribution by E. C. F. Bird of the Australian National University. Late in 1964, Bird released a book entitled Coastal Landforms which was a coastal geomorphology text with Australian examples. This work covers many aspects of coastal geomorphology and contains a ten-page discussion of shore platforms. The shore platform section gives an indication of present state-of-the-art of study in the field.

Bird recognized three types of shore platforms: "inter-tidal", "high-tide", and "low-tide". Inter-tidal platforms were described as extending "from high tide mark, at the base of the receding cliff, to a level below and beyond low tide mark, in the near-shore zone". Bird characterized high-tide platforms as being well developed features located at about high tide level on cliffed headlands. Conversely, low-tide platforms were mentioned as developing "at, or slightly above, low tide level, where cliffs have been cut into lithified Pleistocene coastal dune formations".

The intertidal platform, according to Bird, is a true wave-cut feature which develops and widens as the cliffs recede. The platform is cut as wave action moves sediments across the rock at constantly changing tidal levels. Bird noted that wave-cut platforms on a tideless coast would extend from the cliff base at the water's edge to a depth of thirty feet offshore and would have an average inclination of 1°. In this case the platform would only be about one third of a mile wide, but as the width increases with tidal range, a range of sixteen feet could produce a platform half a mile wide. Bird suggested that a wave-cut platform may be forming at the base of the high-tide platform, so that "the steep drop characteristic of the outer edge of the high-tide platform is essentially a receding cliff at the back of a developing wave-cut intertidal platform".

Bird considered the high-tide platforms to be the result of water-layer weathering processes acting on an emerged wave-cut platform, rather than the product of storm waves. Storm wave formation, he felt, was improbable for several reasons: "...it is difficult to see how occasional storm wave abrasion can cut an almost horizontal surface at high tide level across strata that are tilted or folded. Another difficulty is that high-tide platforms are often as well, or better, developed on sections of the coast that are sheltered from the effects of storm waves".

Water-layer weathering was attractive to Bird as an explanation of horizontality but he thought that this process was not likely to be responsible for extensive cliff recession. He mentioned the possibility that the water-layer weathering was lowering and flattening a platform developed originally as a sloping wave-cut feature. This wave-cut platform, Bird continued, may have been created during an earlier higher sea level and then been exposed by a recent emergence. Bird noted that the occurrence of "degraded cliffs, not kept fresh by marine attack" tends to support this view. He emphasized, however, that the high-tide platforms were not in themselves proof of recent emergence as they can be explained by contemporary processes acting at present sea level.

Bird ended his treatment of shore platforms with a discussion of low-tide platforms. He stated that "These platforms, developed on coastal limestone outcrops, are evidently shaped partly by wave abrasion and partly by solution" and cited the work of Emery as an indication of the process involved. Bird added that the limestone may be attacked more vigorously in the surf zone where the content of atmospheric gases is higher than in still water. He concluded that "the sloping inter-tidal platform that would be developed by wave abrasion appears to have been modified by the effects of solution, so that a broad platform has developed close to low tide level".

This commentary by Bird presents a good picture of the theories current among students of shore platforms. Although the contemporary views are based on a century of study, they seem little changed from the ancestral opinions of Dana and Gilbert. The development of shore platform technology is strangely static, especially in this age where fantastic spurts of scientific progress are taken for granted. Recently, however, the pace has shown signs of quickening. Workers, many from outside the field of geomorphology, are applying advanced techniques to the study of problems associated with shore platforms. Effective geomorphological, biological and chemical methods have joined the traditional description in the attempt to isolate and explain the causes of shore platform development.

SECTION II

DESCRIPTIONS OF TASMANIAN SHORE PLATFORMS

INTRODUCTION

About two-thirds of the Tasmanian coastline was visited in the examination of shore platforms over a three year period. The goal of the field study was to describe the sub-aerial and sub-marine platform morphology in as much detail as possible to furnish a basis for the analysis of formational factors.

Methodology

The basic technique used in the field program was the measurement of platform characteristics by means of surveying instruments. The information received was then plotted on maps and profiles. Detailed surveys on most of the platforms were accomplished with a Wild TO theodolite, but if the platform was difficult of access a Brunton Pocket Transit was used. Plane tables were not utilized because of their vulnerability to rain, spray and high humidity.

The first task in measuring the platform was often the establishment of a traverse to tie noteworthy features to the same datum and establish their spatial relationships. A number of bench marks were located, some of which were erratics in the platform surfaces and others which were chiseled into the surfaces themselves. The longest traverse was established at Eaglehawk Neck and is shown on Figure 2.

Upon completion of the traverse it was necessary to define the datum in terms of sea level. The procedure was complicated by the lack of triangulation nets in Tasmania. To solve the problem a portable tide gauge was designed and constructed to obtain a datum directly at the platform sites. The gauge was installed near the platforms and allowed to run while the surveying was taking place, generally over a period of several days. (For details of construction and operation of the tide gauge, please see Appendix 1).

Three platforms, Silver Gull, Waffle Iron, and Nuroo Island were surveyed in detail to provide a basis for the production of contour maps with an original scale of 10 feet to the inch and contour intervals of either 6 inches or 1 foot. Angular measurements, levelling and distance measurements were all done by theodolite, using the stadia method.

Mapping offshore depended on surveying, depth sounding, diving and aerial photography. A sailing dinghy, with a stadia rod stepped in place of a mast and equipped with an echo sounder, was tracked with the theodolite in the Eaglehawk Neck area. A field assistant rowed the dinghy and operated the echo sounder while a plot was made of the position from shore by noting azimuth and distance. Other soundings were made using a recording unit mounted in a yacht, positioned by hand bearing compass and sextant (Figure 7). Useful information was also gained by underwater inspection and photography using a Nikonos submarine camera.

Air photo interpretation was extremely valuable in the charting of the offshore topography and mapping in general. Available 10 and 20 chain to the inch photos were useful, but a need was felt for a larger scale coverage. As a result, a light aircraft was chartered and a series of large scale, black and white stereo photos obtained. (For discussion of techniques involved in light aircraft stereo photography, please see Appendix 2). Color coverage was made at the same time which, though not in stereo pairs, proved to be helpful in the interpretation of underwater features.

Field study showed that the Tasmanian shore platforms may be grouped according to the horizontality and uniformity of their surfaces and the height at which the platform occurs, as explained in the preliminary introduction. The Table on page 122 lists significant platforms by these criteria and also presents the geographic location and bedrock variety. Platform descriptions in this section are divided into two parts on the same basis of horizontality of surface. Part One includes platforms which have horizontal surfaces and Part Two contains descriptions of sloping platforms.

The wealth of information which the Tasmanian coast offers is almost a disadvantage in that it is difficult to select only a few platforms for description when so many others also appear noteworthy. However, description will be limited to 13 platforms, which are representative of the major Tasmanian platform types. All of the

PART ONE

PLATFORMS WITH HORIZONTAL SURFACES

descriptions will follow the same organizational pattern. First to be discussed will be the location, general geological and geomorphological setting, and environmental considerations (climate, waves, and tides). When these conditions have been established, the platform itself will be described and formational processes briefly examined. This order of presentation has been chosen because of the tremendous influence exerted by structure and environment over platform development. A more detailed and systematic review of processes active in shore platform production will be made in Section III where field results will be combined with information gained from experiments and the literature.

TASMANIAN BEDROCK SHORE PLATFORMS

DESCRIBED IN THIS SECTION

PLATFORM	ALTITUDINAL LOCATION	ROCK TYPE
Horizontal Platforms - Smooth Surface		
Eaglehawk Neck Area		
Silver Gull Platform	High Tidal	Permian Sandstone
Waffle Iron Platform	High Tidal	Permian Sandstone
Nuroo Island	High Tidal Supratidal	Permian Sandstone
Submarine Platforms	Subtidal	Permian Sandstone
Kangaroo Bluff Platform	High Tidal	Permian Sandstone
Cape Grim Platforms	High Tidal Supratidal	Tertiary Basalt
Don Heads Platform	High Tidal	Tertiary Basalt
Horizontal Platform - Rough Surface		
Weymouth Platform	High Tidal Supratidal	Tertiary Basalt
Sloping Platforms		
Tasman Island Platforms	Supratidal	Jurassic Dolerite
South Croppies Point Platform	Supratidal	Tertiary Basalt
Grant Point Platform	Supratidal	Devonian Granite
St. Helens Platform	Intertidal	Devonian Granite
Apex Point Platform	Transgressive	Jurassic Dolerite

Chapter 3

EAGLEHAWK NECK PLATFORMS

Field work for this study of the development of Tasmanian shore platforms was concentrated in the Eaglehawk Neck area of the Forestier Peninsula, thirty air miles southeast of Hobart. This location was selected because it contained a number of well developed horizontal, high tidal platforms. The platforms occur in a variety of wave environments, ranging from sheltered to completely exposed, which favored the study of the relationship between platform morphology and exposure to wave attack. Another advantage of the site was the presence of a small island, fringed by platforms, which allowed the effects of the continuous transition from high to low wave energy to be observed.

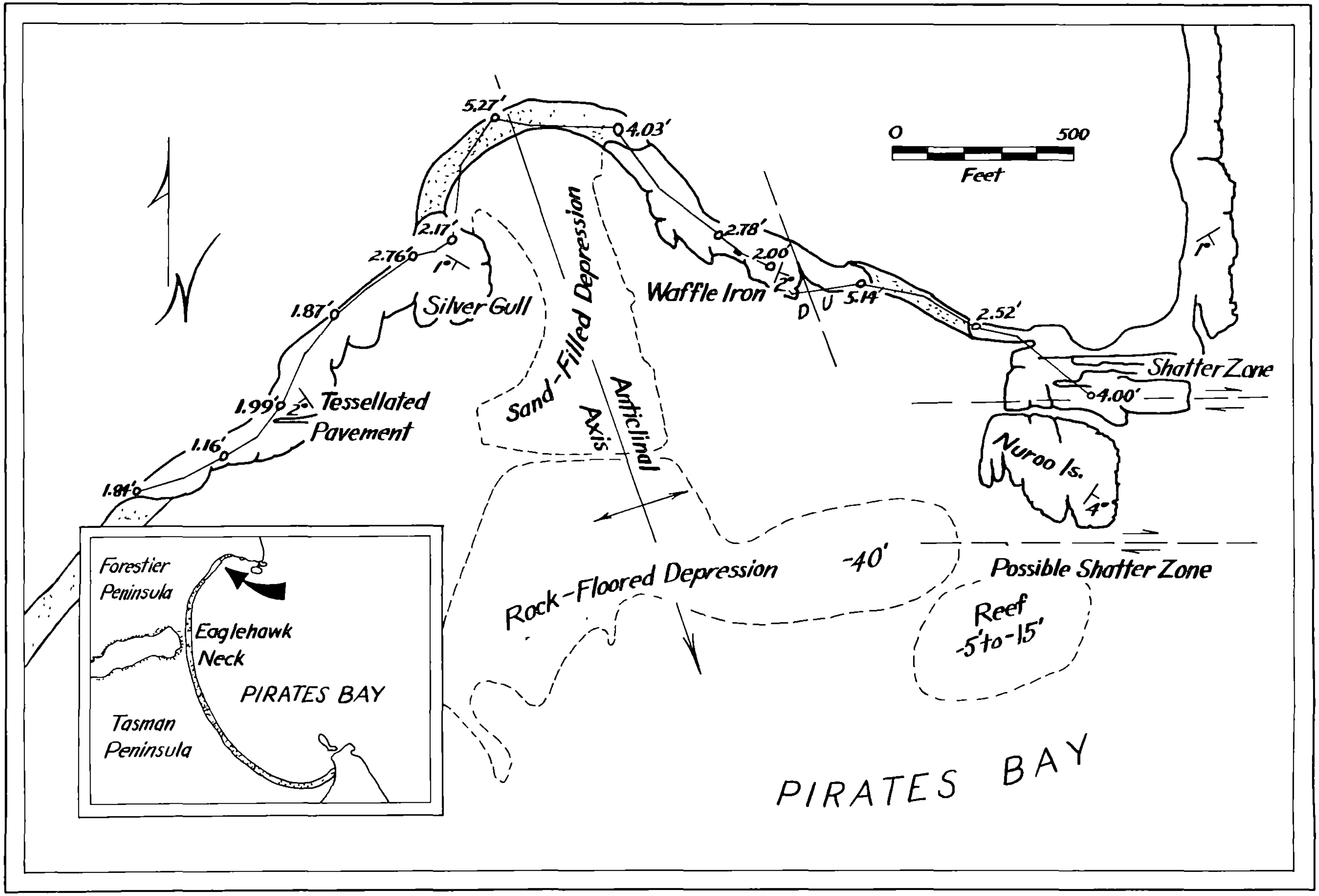
STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

The most extensive platforms in the Eaglehawk Neck area are in the northern bight of Pirate's Bay, an indentation about a mile and a half long and three quarters of a mile wide. The platforms are sheltered in all directions except to the southeast where they are exposed to the open sea. Most of the Pirate's Bay shoreline is composed of sand, with occasional rock outcrops supporting platforms. However, sand occupies only a limited area in the north part of the bay where platforms are almost continuous.

Figure 2

EAGLEHAWK NECK PLATFORM LOCATIONS, SURVEY TRAVERSE

AND GEOLOGICAL SKETCH MAP



5.27'
4.03'
0
500
Feet
2.17'
2.76'
1°
2.78'
2.00
2°
D
U
5.14'
2.52'
1.87'
Silver Gull
Waffle Iron
Sand-Filled Depression
Anticlinal Axis
1°
Shatter Zone
4.00'
1.99'
2°
Tessellated Pavement
1.16'
1.81'
Nuroo Is.
4°
Forestier Peninsula
Eaglehawk Neck
PIRATES BAY
Tasman Peninsula
Rock-Floored Depression
-40'
Possible Shatter Zone
Reef
-5' to -15'
PIRATES BAY

The platforms and cliffs have been cut in Permian siltstones and sandstones of the Malbina and Risdon Formations. These rocks show a very well developed system of joints which vary in frequency and direction but which exhibit an intersector which remains constant from bed to bed (Tasmania Dept. of Mines, 1965). Bedding is well defined, with bed thickness varying in general from 1 to 3 feet.

Faulting and folding has occurred in the area, but disturbance of the original bed horizontality has been slight. Dips vary from 1° on Silver Gull and Fossil Cliff platforms; through 2° on the Waffle Iron platform; to 4° on Nuroo Island. Cause of the varying dips was the gentle arching of the formations into a plunging anticline with an axis running roughly northwest-southeast. The platforms under examination flank the axis of this anticline, which is expressed topographically as a gully, sandy beach and submarine depression. Both strike slip and dip slip faults are present, with displacements ranging from fractions of feet to several yards. The faults tend to have axes of either 90° or 160° and are apparently related genetically to the joint patterns.

The platforms are all backed by cliffs which vary in height from 20 feet to 100 feet. Some of the cliffs are vertical and even locally overhanging, but others have a less steep gradient with a soil cover. The cliffs nearest Eaglehawk Neck form the seaward limit of a sloping, vegetated terrace, while the cliffs on the opposite side of the anticline drop from a higher, less even area.

Submarine Topography.

Local submarine topography consists of a series of rock platforms at different levels interspersed with patches of sand. The submarine platforms range in depth from low tide level to about -50 feet msl with distinct jumps in elevation between the horizontal surfaces. A reef centered approximately 400 feet southeast of Nuroo Island is the one exception to the general pattern of increasing depths seaward. The reef is composed of a series of platforms, the uppermost of which is at -5 feet msl, and is separated from Nuroo Island by a trench lying at a depth of -15 feet. Orientation of the trench is similar to the positioning of the channels between Nuroo Island and the mainland and may be the expression of a shatter zone associated with faults in the area. Platforms below -30 feet msl support fairly dense stands of giant kelp (*Macrocystis*) while shallower platforms are literally covered with smaller forms of coralline and non coralline algae such as *Lithothamnion* and *Durvillea*.

CLIMATE

The Eaglehawk Neck area, in common with the rest of Tasmania, has a temperate marine climate. In the Thornthwaite classification

Eaglehawk Neck is Warm-Humid with a temperature efficiency of 70 and a precipitation effectiveness of 64.[1] The southeast coast is generally sub-humid due to rainshadow effect, but Eaglehawk Neck is far enough south to avoid the full effect of this phenomenon as is shown by the presence of a small patch of rain-forest vegetation in the vicinity.

Precipitation.

Precipitation in the study area probably averages about 40 inches per year, on the vegetational evidence, but no precise data are available. A rain gauge near the low-lying neck about a mile to the southwest records an average of 35 inches per year, with a reduced orographic effect, indicating that a figure of 40 inches could be attained on the platforms which are backed by steeply rising slopes.

Snow is rare, and precipitation is chiefly in the form of rain which is distributed throughout the year in amounts which show some seasonal variation. Rainfall is least in late winter when the westerlies are strongest and in the summer when the westerlies are relatively absent. Precipitation maxima occur in autumn and spring when cyclonic pressure centers affecting the eastern part of

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[1]Unless otherwise noted, climatic data in this thesis was obtained from the Tasmanian Regional Planning Atlas (1947), the Atlas of Tasmania (1965) J.L. Davies ed., and the Bureau of Meteorology, Hobart.

Tasmania are most prevalent. In 1966, for instance, five such disturbances caused storm conditions with rain and strong south-easterly winds. (One occurred in June, one in July, one in September and two in October).

Temperature.

Temperatures are generally moderate with only the three winter months having averages below 50°F. Maximum temperatures recorded on the southeastern coast have topped 100°F., but this is not a very common occurrence. No temperature records are kept at Eaglehawk Neck, and the closest recording station is at the Tasman Island lighthouse, about 16 miles to the south. Unfortunately, Tasman Island has a far more maritime temperature regime than Eaglehawk Neck. In addition, records have only been kept since 1965, creating a possibility of error in assessing the actual long-term conditions from available data. January, the hottest month in the year, had a 1965 average maximum temperature of 57.4° and an average minimum of 49.5°. Another station, Swansea, is located about 60 miles to the north of Eaglehawk Neck on a large bay. Temperatures here show the influence of the surrounding land mass and warmer water, with a long-term average maximum of 71.5° and a minimum of 54.8° for January. Eaglehawk Neck values are probably considerably closer to the Swansea measurements and probably average about 68° maximum and 52° minimum for January.

Winter temperatures also show the insular position of the Tasman Island readings, with averages of 49.6^{o} and 41.6^{o} for maximum and minimum in July. In Swansea that month yields values of 52.1^{o} and 38.8^{o} respectively. Again, Eaglehawk Neck temperatures could lie somewhere in between, approximately 50^{o} for the average maximum and 40^{o} for the average minimum. Frost is possible for six months of the year in southeastern Tasmania, but as the lowest recorded temperature in the district was above 25^{o}F., conditions would not be severe enough to be significant on platforms in a sea-level, salt water environment.

Evaporation.

Evaporation, important to water-layer weathering processes, is fairly high in the coastal areas of southeastern Tasmania. High annual wind travel and ample sunshine (about 2,100 hours per year) combine to evaporate an average of 31.51 inches of water yearly from the surface of a sunken test tank at Kelvedon, near Swansea. The seasonal variation in evaporation is quite marked, with the January average evaporation figure reaching 4.90 inches and the July reading dropping to only 1.00 inch. (All values must be multiplied by 1.32 to convert from Australian evaporation pans to American "A" pans). Eaglehawk Neck evaporation should be only slightly less than the Kelvedon figures.

Winds.

Winds at Eaglehawk Neck are generally either northwesterly or southeasterly, depending on the month of the year and the time of day. In summer, there is a general pattern of light morning northwesterly land breezes, stronger afternoon southeasterly sea breezes (15 to 20 knots) and nightly calm. This pattern is frequently broken, however, by a strong northwesterly flow which may completely over-ride the sea breeze regime. Winter winds are more uniform in direction until affected by the passage of a cyclonic disturbance. Northwesterly winds predominate, with insufficient heating in the interior to create a sea breeze. During cyclonic conditions, the northwesterly flow is replaced by southeasterly winds which may reach gale force.

The southeasterly gales are produced by a combination of an intense high pressure area in the Great Australian Bight and deep lows in the Tasman Sea. Moisture laden air is pumped with great force against the southeastern Tasmanian coast along with waves that may reach 25 feet in height. An observer watching the driving rain and spray is immediately impressed with the erosion potential of this condition.

WAVE CHARACTERISTICS

Storm Waves.

Very large storm waves are possible during southeasterly storm conditions because of the large fetch available. The attainable fetch is actually several thousand miles - to Antarctica, but the cyclonic circulation is usually such that strong southeasterly winds only blow over about 600 miles at the most before hitting Tasmania. A 600 mile fetch and gale force winds could combine to form truly formidable seas. Using Bretschneider's (1952) tables, a 40 knot wind blowing over 600 miles for 30 hours could produce waves having significant heights of 27 feet. Personal estimates of the heights of unbroken storm waves at Eaglehawk Neck were only about 12 feet, but these waves were markedly oversteepened and apparently not fully developed.

Local fishermen remarked that the storms observed were fairly mild and that in really good disturbances spray is hurled completely over the top of Nuroo Island, 52 feet high. Fishermen also tell of a 20 foot long cray dinghy which was moored in 10 feet of water between the Silver Gull platform and the Waffle Iron platform. A breaking wave during a storm caught the dinghy, tore loose the moorings and hurled the boat up on the beach where it was destroyed in the surf.

If the water were actually 10 feet deep, the wave which swamped the dinghy could have been 8 feet high before it broke. Waves in this partially sheltered area never reached heights above 4 feet during the storms personally watched, when waves on the exposed shoreline were about 12 feet high. Fishermen's data is difficult to quantify at the best of times, but fragments of dinghy and the large tree trunks half buried at the rear of the small beach attest to occasional high wave energies in this cove. Consequently, it seems probable that waves having an unbroken height of 15 feet for the average of the highest 10% may occur on this coast during exceptionally well developed southeasterly storms about every five years. As a very rough estimate, waves 25 feet high may strike during phenomenal conditions once during 100 years.

Swell and Sea Breeze Chop.

Except for the relatively few times every year when the southeasterly gales sweep the coast, waves in the Eaglehawk Neck area are fairly low in energy. Most prevalent wave type is the once mighty southwesterly swell which has been refracted almost beyond recognition around the tip of Tasman Peninsula. This remnant swell, seldom more than three or four feet high offshore, is the constant background upon which other waves striking the coast are superimposed. In the summer, the swell is joined by chop produced by afternoon sea breezes. The chop rarely reaches heights above 3 feet because the sea breeze is a local phenomenon acting over a short time span. Northwesterly winds also produce waves in the Eaglehawk Neck area, but these are proceeding seaward from the coast and have no effect on the shoreline.

TIDAL REGIME

Tides in Pirate's Bay were measured over a period of several months by a portable recording tide gauge during the 1957-58 International Geophysical Year. Based on this operation, data in the Admiralty Tide Tables show that the form is mixed, predominantly semidiurnal ($\frac{K_1 + O_1}{M_2 + S_2} = 1.01$) with two high and two low waters daily having pronounced inequalities in height and phase. Mean higher high water is 4.3 feet, mean lower high water is 3.5 feet, mean higher low water is 2.5 feet and mean lower low water is 1.7 feet. These figures yield a mean range of only 2.6 feet between mean higher high water and mean lower low water. For present purposes, mean sea level can be taken with sufficient accuracy to be 2.6/2 feet or 1.3 feet, putting mean higher high water at 1.3 feet msl.

SILVER GULL PLATFORM

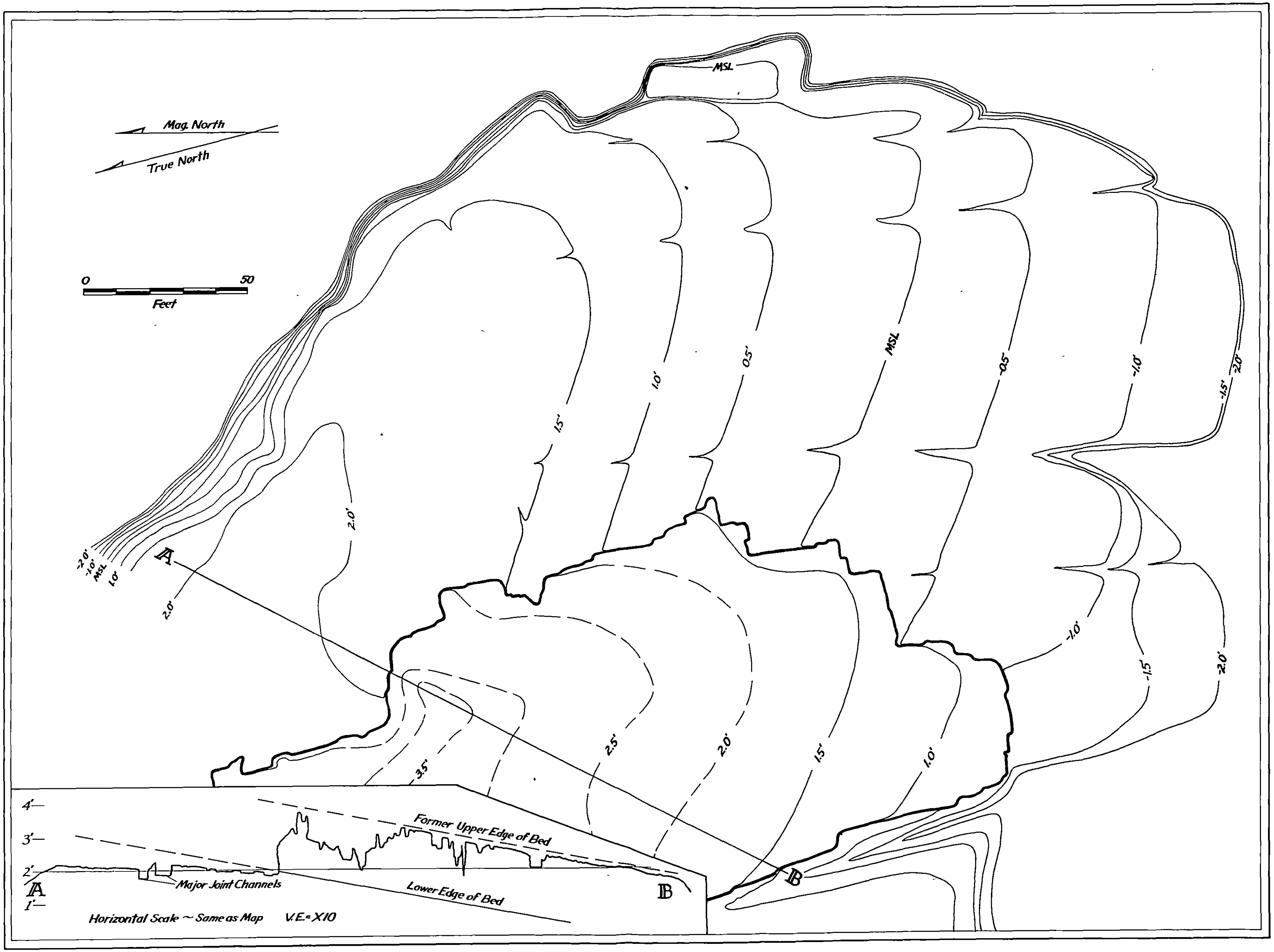
The first platform to be surveyed in detail was the "Silver Gull" platform, located in the extreme northwestern corner of Pirate's Bay. The platform was named for reference in honor of the noisy colony of silver gulls (Larus novohollandii) which considered it their domain. Roughly oval in shape, the Silver Gull platform has a dimension along the major axis of 340 feet and along the minor axis of 240 feet, with a total area of about 81,500 square feet. A depressed area filled with sand flanks the platform on the east, while a joint channel and a cliff descending to a submarine platform form the western and southern boundaries. The landward border of the platform to the northwest is indistinct because of sand cover which reaches the foot of a sloping surface. Soil and vegetation mantle the slope, which extends to an elevation of approximately 25 feet with an average inclination of 45^{o}.

Wave Activity.

Wave activity on the Silver Gull platform is usually not pronounced except during southeasterly storms. Refracted southwesterly swell and sea breeze chop combined only on rare occasions attain heights here of over three feet. The partial shelter of the offshore reef and the presence of kelp to seaward which limit these heights also act to reduce wave energy reaching the platform during storms. A maximum wave height of eight feet may occur during particularly violent storms spaced several years apart.

Figure 3

CONTOUR MAP AND PROFILE OF SILVER GULL PLATFORM



Mag. North
True North
0
50
Feet
MSL
-2.0'
-1.0'
MSL
1.0'
2.0'
A
2.0'
1.5'
1.0'
0.5'
MSL
-0.5'
-1.0'
-1.5'
-2.0'
3.5'
2.5'
2.0'
1.5'
1.0'
-1.0'
-1.5
-2.0'
B
4'
3'
2'
1'
Former Upper Edge of Bed
Major Joint Channels
Lower Edge of Bed
A
B
Horizontal Scale ~ Same as Map
V.E.= X10

Geology.

The Silver Gull platform is formed entirely within two beds of Permian sandstones. Although the top of the upper bed has been eroded, detailed profiling suggests that it was originally about 2 feet thick. The underlying bed also appears to have approximately the same thickness. Distinct jointing is present in the beds underlying the Silver Gull platform, as elsewhere in the Eaglehawk Neck area. However, jointing is not the very striking feature here as it is on platforms to the southwest and northeast. Jointing is generally rectangular, with the blocks outlined being about one foot square.

The beds strike N 58° W (122°) and dip 1° S 32° W (212°). Upon first consideration, it may seem that beds which are so close to being horizontal would not offer much information on platform genesis beyond some evidence for wave stripping. Wave stripping along bedding planes has certainly occurred, but this activity leaves a surface sloping exactly as the dip. Mapping has shown tendencies, at certain levels, for the surface to become horizontal across the dip of the bed. Because this levelling occurs within one bed of a uniform rock type, the low dip may actually be advantageous in that it reduces the number of variables which would be encountered when several beds of differing characteristics were bevelled.

Bevelling of Beds.

The large scale contour map (Figure 3) and the profile both show the levelling tendency, although different aspects are emphasized on the two presentations. The map indicates the horizontality produced in the upper surfaces of the beds and the profile shows the base level to which pitting occurs. Pitting base level and level of horizontality lie in a zone between 1.8 feet and 2.3 feet msl, with most widespread expression at 2.0 feet. As noted earlier, mean higher high water lies at an elevation of 1.3 feet msl. Horizontality then occurs between 0.5 feet and 1.0 feet above mean higher high water with best expression at 0.6 feet above this level.

The map, compiled from numerous theodolite observations, clearly demonstrates the bevelling in the lower bed. The surface slopes uniformly upward with the dip of the rock from -1.5 or -2.0 feet on the south and southwest side of the platform until the +1.5 contour is reached. Here the pattern of fairly even contour spacing is disrupted and levelling is indicated by a much longer horizontal distance between the +1.5 and +2.0 foot contours. No point on the northern corner of the lower bed rises higher than 0.5 foot above the +2.0 level. It can be seen that the dip remains reasonably constant by tracing the bedding plane between the upper and lower beds in this region.

Photograph 1

Aerial view of Silver Gull Platform

Photograph 2

Surface view of Silver Gull Platform. The lower bed has been bevelled to saturation base level by sub-aerial weathering. The upper bed is being removed by quarrying and weathering.

Mapping.

Mapping of the top surface of the upper bed offered more difficulties than did the lower bed. Although the lower bed was pitted, depressions were generally less than a few inches deep and the surface was fairly even. However, pits in the upper bed surface were more extensive and were sometimes over a foot deep, complicating mapping considerably. The approach finally adopted was to choose the highest points on the surface for theodolite stations from which to construct the map. Detail, it was felt, could be better shown by a profile which would not be limited by the 0.5 foot contour interval.

The profile was plotted along a line bearing 220° true, located on the northwestern end of the platform. This placement took the profile exactly down the dip of the beds and included both the regularly surfaced, bevelled lower bed and the deeply pitted upper bed. Readings were obtained with theodolite and rod at every point where a change in slope occurred. Intermediate determinations were made where slope changes were more than about a foot apart. The profile covers a vertical range of 2.6 feet over a length of 200 feet. Because the profile contains such a narrow spread over a long horizontal distance, it was necessary to exaggerate the vertical scale to a value ten times larger than the horizontal scale.

Interpretation.

Starting at "B" on the southwest corner of the platform, the surface rises steadily with the dip for approximately 40 feet with little pitting evident. A major joint channel is then encountered which shows a flat bottom at +2.0 feet msl. Pitting is relatively absent for another 10 feet at which time the surface has reached a height of 2.6 feet. Northeast of this location, pitting is fairly continuous until the edge of the bed is reached, some 70 feet further along. This zone shows great surface irregularity although a concordance of remnant rock summits indicates the previous top of the bed. Some of the pits are quite large, several being over 4 feet across, but in no instance does the pitting extend below a level of +1.7 feet.

The marked horizontality of the lower bed surface is also indicated on the profile. Over a span of 65 feet the surface varies only 0.3 foot, from 1.9 feet at the edge of the upper bed to 2.2 feet on the northwestern boundary of the platform. Pitting is much less pronounced on this lower bed, with most occurring in conjunction with joints. Even in the joints, however, no removal of material has taken place below +1.7 feet.

Organisms.

The Silver Gull platform sustains abundant plant and animal life. In general, there are four distinct biotic zones represented.

Using the terminology of the intertidal ecologists (Bennett and Pope, 1960) they are the supra littoral, the upper and lower mid littoral and the infra littoral. The lowest zone, the infra littoral, is located below -1.5 feet and is dominated by the giant fucoid, *Durvillea potatorum*. Another prominent resident of this zone is the bright pink lithothamnion which encrusts any rock surfaces left uncovered by the *Durvillea* holdfasts. The lower mid-littoral zone, between -1.5 feet and mean sea level, contains many coralline algae. *Lithophylum* and *Corallina* are common, together with the chiton *Poneroplax costata* and the limpet *Siphonaria diemenensis*. Further up the slope, from mean sea level to about 3.0 feet is the upper mid-littoral zone characterised by the very adaptable periwinkles including *Melarapha praetermissa* in the lower parts and the smaller *Melarapha unifasciata* in higher locations.

The highest zone of all, the supra-littoral above 3.5 feet msl, is distinctly different from the previously mentioned areas. All of the lower zones contained plant and animal life which is marine in origin. Above 3.5 feet, however, occurs a terrestrial species of orange lichen, *Gasparinnia murorum*, distinctly different ~~than~~ from the marine algae which coat the rock surfaces at lesser elevations.

Although definite zones exist on the platform, some organisms may range over two or more boundaries in their occurrence. The chitons and limpets, for instance, can be found from the bottom of the mid-littoral zone through to the upper mid-littoral zone on the exposed rock surface. Tidal pools on the platform also offer a means whereby species may transgress into other elevational zones.

Factors in Formation.

The Silver Gull platform exists at present in response to a number of factors, some of which are forces and some of which are physical characteristics of the platform itself. In very general terms, the forces are wave energy and various types of weathering and the physical characteristics are rock type, bedding and jointing.

A basic consideration in the formation of the Silver Gull platform (as in all rock platforms) is the presence of a rock type suitable for platform production. The Permian sandstones from which the platform is carved are porous, permeable, well bedded and jointed and break down under weathering attack fairly readily. Although in these respects the rock is relatively weak, it is not so delicate that it can be immediately eroded by water action or occasional rock abrasion.

Important factors controlling the platform morphology are the characteristics of bedding and jointing, amount of wave energy available, and intensity of weathering. These three factors have joined in an intricate relationship in the formation of the Silver Gull platform. In very broad terms, weathering intensity and bedding, including strike, dip and bed thickness, are important to the development of the cross sectional profile on the Silver Gull platform while jointing influences the horizontal dimensions.

Wave activity helps shape the gross platform morphology through quarrying and transportation of material derived both from hydraulic action and weathering. Some wave-activated abrasion may take place as the quarried material is moved into storage, but the general absence of tool rocks on the platform surface and the angularity of exposed bedrock surfaces indicate that rock abrasion is not a very potent factor on this surface.

Jointing and Wave Action.

The plan form of the Silver Gull platform is controlled by jointing and removal of blocks by wave activity. The effect is most pronounced on the northeast and east sides of the platform where disruption of beds in the vicinity of the anticlinal axis has encouraged erosion to the extent that no bedrock is visible for a horizontal distance of 500 feet eastward. Jointing on the other boundaries of the platform has also aided the work of erosive forces, but bedrock is still present at slightly lower levels. Blocks quarried from the areas surrounding the major joints have in most cases been pushed into storage at the foot of the cliff to the northwest of the platform. Some blocks, however, lie on the submarine platform seaward and others can be seen flanking the Silver Gull platform on its northeastern edge.

The top surface of the platform has also been subject to the removal of material by wave action, with the process continuing at present. Until the level is reached at which weathering is an active force, the platform surface rises with the dip and corresponds to the upper limit of the underlying bed. The cross sectional profile is dictated by the dip and the bed thickness where wave quarrying has taken place and is only significantly modified by weathering in the zone above 1.5 feet msl. Quarrying along joints has produced a rectilinear pattern on the southern edge of the upper bed.

Contemporary stripping of the upper bed from the platform is indicated by the freshness of the edge of that bed and the presence of blocks newly detached from the bed's seaward edge. The blocks are quite large and have not moved noticeably in the two years in which they have been under observation, but no really severe storm has occurred in that period. It is quite possible that conditions violent enough to shift these masses of rock develop only rarely, with years of less severe conditions intervening.

Weathering.

While quarrying takes place only intermittently, weathering is continually modifying the surface of the platform. Weathering on the Silver Gull platform is of two basic types, mechanical and chemical. Mechanical weathering includes wetting and drying phenomena and salt crystallization (basically the water-level weathering processes of Wentworth), and biological activity. Chemical weathering, less important to the formation of the Silver Gull platform surface, consists of chemical solution and hydration of constituent minerals with important aid from biochemical reactions.

The most prominent evidence for weathering on the Silver Gull platform is the horizontality of the part of the lower bed above +1.5 feet msl and the uniform base level of pitting on the upper bed. In both cases, lithology and structure do not appear to offer any explanation for the bevelling. Some quarrying of smaller blocks may have taken place in this area, but it would be difficult to explain the bevelling of the beds between bedding planes through this agency. Rock abrasion is also improbable as there are no loose tool rocks present on the platform surface and no obvious indications of abrasive activity. In addition, the deep, narrow pitting would be beyond the capability of abrasive rock erosion in this environment.

Sub-aerial weathering to a base level remains as the most reasonable explanation for the horizontality. Many other Tasmanian platforms show a similar horizontality at about the same height - the approximate level of local mean higher high water. If, as Wentworth and others have suggested, water-layer levelling depends on repeated wetting and drying for its operation, then the base level of pitting and the horizontality of the Silver Gull platform may be due to weathering to a level of permanent saturation in the rock. Saturation would forestall further weathering by limiting salt crystallization which depends on repeated evaporation of water. Evidence is shown on the profile for saturation of the rock at a level between 1.5 feet and 2.0 feet on the Silver Gull platform. Many of the pits extending to this zone have water standing in the bottoms, while only a few of the pits in the higher areas contain water.

Sub-aerial weathering through wetting and drying would have had to work quickly on the Silver Gull platform to produce horizontality in the face of all the other factors which are attempting to degrade the surface. Quarrying, occasional rock abrasion and sand abrasion are the more obvious forms of erosion threatening the level portion of the platform, but other more subtle processes are also active. Chief among these are biological and biochemical activities.

Biological Erosion.

Biological erosion on the Silver Gull platform operates in two different ways. Chitons, such as *Amaurochiton glaucus* and *Poneroplax costata* and limpets represented by *Siphonaria diemenensis* actually create pits in the platform surface as much as 1/4 inch deep. They occupy these pits during low tide and range higher with the incoming tide in search of algal food. The mechanism of boring is not readily apparent, but it is likely to be either chemical solution of the rock by mucus or erosion by shell-rocking or movement of mantel spicules. Other organisms, especially the periwinkles of the genus Melarpha, mechanically remove the rock surface in rasping loose the tightly adhering algae upon which they feed. It is difficult to assess the total erosion attributable to these organisms, but Emery (1960) has calculated that periwinkles alone could dislodge a layer of rock one foot deep every 1200 years in sandstone.

Biochemical Activity.

Biochemical activity in tide pools is another type of erosion which is present on the Silver Gull platform, though in limited areas. Tidal pools in joint channels occur on the southern end of the platform at elevations from about mean sea level to -1.0 feet. The pools contain large communities of plant and animal life and all conditions for instituting pH changes and subsequent solution are present.

Future Development of Platform.

The discussion of the Silver Gull platform up to this point has concerned the platform as it exists at the present. This contemporary morphology is the result of a number of forces which interacted in the past to develop the platform. The sea probably had considerable importance in this development, but it is not possible to ascribe the platform completely to wave activity. It is more likely that a process of sub-aerial weathering reduced the surface to its present level aided by removal of weathered material by wave action. This process is not yet complete, with the higher, lichen covered areas of the platform still to undergo about two feet of weathering. Wave quarrying, now effective on the lower parts of the platform, was probably not an important force until weathering had weakened the joint and bedding planes.

Ultimate fate of the Silver Gull platform depends on the stability of sea level and atmospheric conditions. If sea level remains at the present height, weathering could eventually bevel the upper bed to about 2.0 feet msl where it would show horizontality similar to the lower bed. Rapid quarrying of the upper bed is a distinct possibility, however, and this action would strip the weathered surface completely down to the lower bed. This eventuality seems the most likely and the resulting platform - with only the lower bed remaining, bevelled at 2.0 feet msl with the seaward surface matching the dip - would exist in a stable configuration for a long period. Ultimately, quarrying and random abrasive forces coupled with chemical, biochemical and biological activity would probably degrade the horizontality and lower the surface inexorably until burial by sand halted the process.

If sea level remained constant and storminess decreased, quarrying would be a less important factor and the weathering profile would prevail, although at a lower level. An increase in storm activity would hasten quarrying, leading to the earlier destruction of the bevelled weathering profile. Such an increase in wave activity might also allow the platform to develop landward. The cliffs at the rear of the present platform are now covered with soil which prevents rapid weathering. If waves contained more energy and were more frequent, this material would be removed. Some quarrying would then also take place, but the most significant activity would be the renewal of sub-aerial weathering.

A rise in sea level would produce a similar result, with increased erosion at the rear of the platform. The present platform would then occupy a position relative to the new surface similar to the lower platforms now found offshore. The sharp outlines created by weathering if still present would be rounded by chemical and biological forces upon submersion. However, it is possible that the rise in sea level would allow effective quarrying to remove the entire deeply weathered upper bed before the water became too deep for significant wave attack.

Platform morphology associated with a fall in sea level would depend on the rapidity and extent of the fall. If the regression was rapid, but not greater than a few feet, the present platform would respond by quickly losing horizontality through weathering to the new saturation level. If the fall in sea level was quick and over a considerable distance, the platform surface might be perched above the zone of most rapid weathering and exist as a fossil form for a relatively long period. In the case of slow regression, the platform surface would maintain overall horizontality because the new saturation level would never be far below the previous elevation.

Numerous other configurations would be possible with combinations of changing weather conditions and shifting sea levels. For example, a decrease in wave activity coupled with a slight rise in sea level could leave the platform surface looking much the same as at present, with a reduction in quarrying preserving the upper bed and weathering operating to a base level held at the same position by a balance between a rise in sea level and lessening of the height reached by waves. A number of other cases can be listed, but they all follow the same pattern: an increase in wave activity or a rise in sea level raises the saturation level and hence the base level of weathering and also lifts the level of effective hydraulic action; a decrease in wave activity or a fall in sea level lowers both the weathering base level and the zone of hydraulic action.

WAFFLE IRON PLATFORM

Another platform which proved to be productive for detailed geomorphological investigation is located 800 feet to the east of the Silver Gull feature. The platform, labelled the "Waffle Iron" because of its peculiar surface of remnant knobs, shows many of the characteristics of the Silver Gull platform - and some pronounced differences.

General Description.

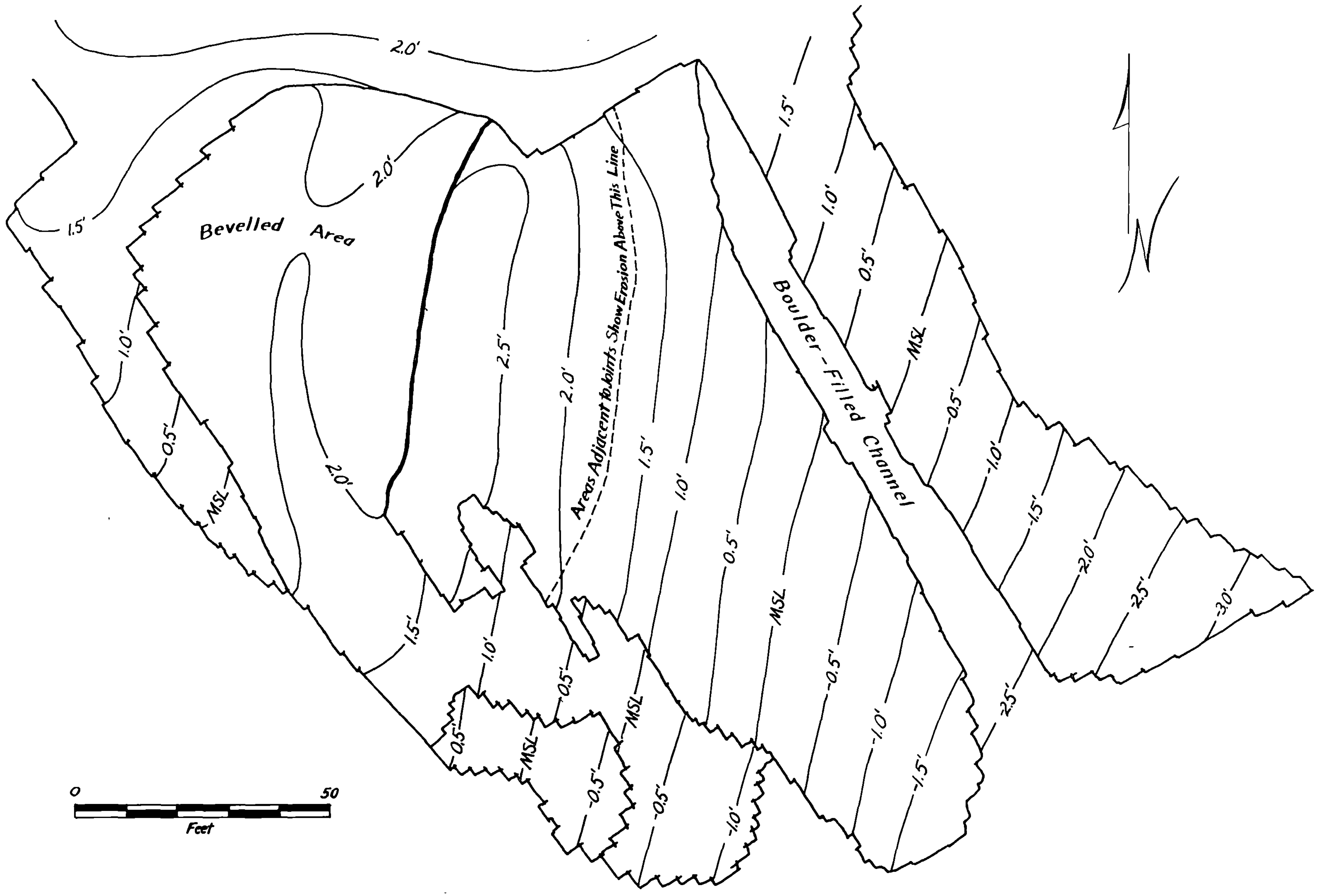
Like the Silver Gull platform, the Waffle Iron is roughly oval in shape with its long axis oriented in an east-west direction and its short axis extending north and south. The Waffle Iron is bounded by a sharp drop to a -3.0 foot submerged platform on the seaward edge, joints or faults from which material has been quarried to the east and west, and a cliff about 50 feet high to the north.

Dimensions of the platform are about 200 by 100 feet, yielding an approximate total area of 20,000 square feet, considerably less than the 81,500 square feet of the Silver Gull feature. Vertical dimensions are also slightly less than the Silver Gull platform, with the highest point on the Waffle Iron reaching 3.56 feet, contrasting with the 3.70 foot altitude attained on the previous platform.

Through being more sheltered by an offshore reef and Nuroo Island, the Waffle Iron is not subjected to wave attack of such

Figure 4

CONTOUR MAP OF WAFFLE IRON PLATFORM


Boulder-Filled Channel
Bevelled Area
Areas Adjacent to Joints Show Erosion Above This Line
0
50
Feet

high energy as the Silver Gull platform. Even the most active storms would probably create waves which were no larger than six feet high by the time they reached this protected position. During more normal conditions the waves produced by refracted southwesterly swell and the sea breezes are seldom higher than two feet in this area.

Rock type on the Waffle Iron is a Permian sandstone, slightly less coarse than the beds composing the Silver Gull platform. Three distinct beds are represented on the Waffle Iron in contrast to the two which were present on the other feature. Each of these beds is a little over a foot thick, with bedding planes very well defined. Because the Waffle Iron is located on the opposite side of the anticlinal axis, the strike is quite different from that on the Silver Gull platform. The strike of the northern platform beds is N 10° E (10°) and the dip is S 80° E (100°), with an angle from the horizontal of 2° (twice the angle found on the Silver Gull platform).

As on the Silver Gull platform, jointing is very important in the formation of the Waffle Iron. All three beds comprising the platform are well jointed, with joint spacings of about one foot common. The joints intersect at angles close to 90° and form almost cubical blocks when quarried. Quarrying is particularly active along the edges of the beds, with some landward incursions forming narrow channels 15 or 20 feet long.

A major channel, the expression of a dip slip fault, runs along the east edge of the Waffle Iron. Displacement along this fault is of the order of 0.5 foot, with the eastern side raised above the western margin. The fault can be traced into the cliff to the north and underwater to the south where it is expressed as the edge of a sand-filled depression. The large channel dividing the Waffle Iron from the adjacent platforms has resulted from the erosion of weakened material in the fault zone and is now choked with quarried rock.

Bevelling of Beds.

The surface of the Waffle Iron follows the dip slopes of the beds until heights of about 1.8 feet msl are reached. At 1.8 feet, horizontality starts to occur which becomes most pronounced on the intermediate bed at an elevation of about 2 feet msl. The surface of the intermediate bed appears to have reached a weathering equilibrium level, but the upper bed has not yet been entirely reduced. Remnants of the upper bed surface occur as small, flat-topped knobs, with the intervening joints depressed as much as six inches.

The surface of the upper bed rises uniformly from -1.5 feet msl to 1.8 feet msl. Jointing is pronounced in this zone, with the joints themselves occupying positions slightly lower in elevation than the blocks they define. At 1.8 feet msl the joint depth, which has been fairly constant, begins to increase. The joint depth gradually increases for 35 feet, when a height of 2.70 feet is reached by the lower surface. The joint blocks in this zone exist as knobs rising four to six inches above the surrounding base level. The joints are flanked by a level area several inches wide which surrounds the remnant blocks. In this higher part of the Waffle Iron, some of the knobs have been removed completely. Many of the interjoint areas are quite level and depressed below small ridges immediately adjacent to the joint planes.

The upper bed drops abruptly to the intermediate bed surface in the middle portion of the platform. The intermediate bed, which has been faithfully following the dip slope, becomes strongly bevelled at a height of approximately 2 feet msl. Quite a large area has been levelled, with dimensions of 50 feet in the north-south direction and 60 feet in the east-west direction. Jointing on the level part of the bed is rectilinear and well developed, with ridges flanking the joints and the centrally depressed areas often containing water. Joints in the eastern portion of the bevelled section are less regular, as are those down the dip slope to the southeast. The surface at lower elevations on the intermediate bed is fairly rough, with depressed joints breaking the continuity.

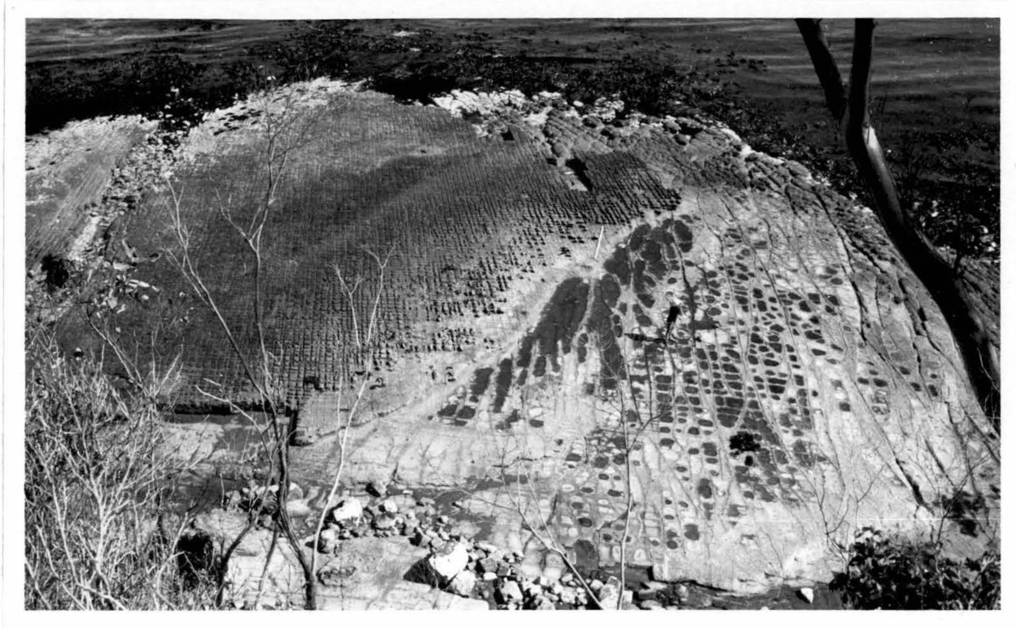
Another bed, the lowest of the three comprising the Waffle Iron, is visible on the northern and western margins of the platform.

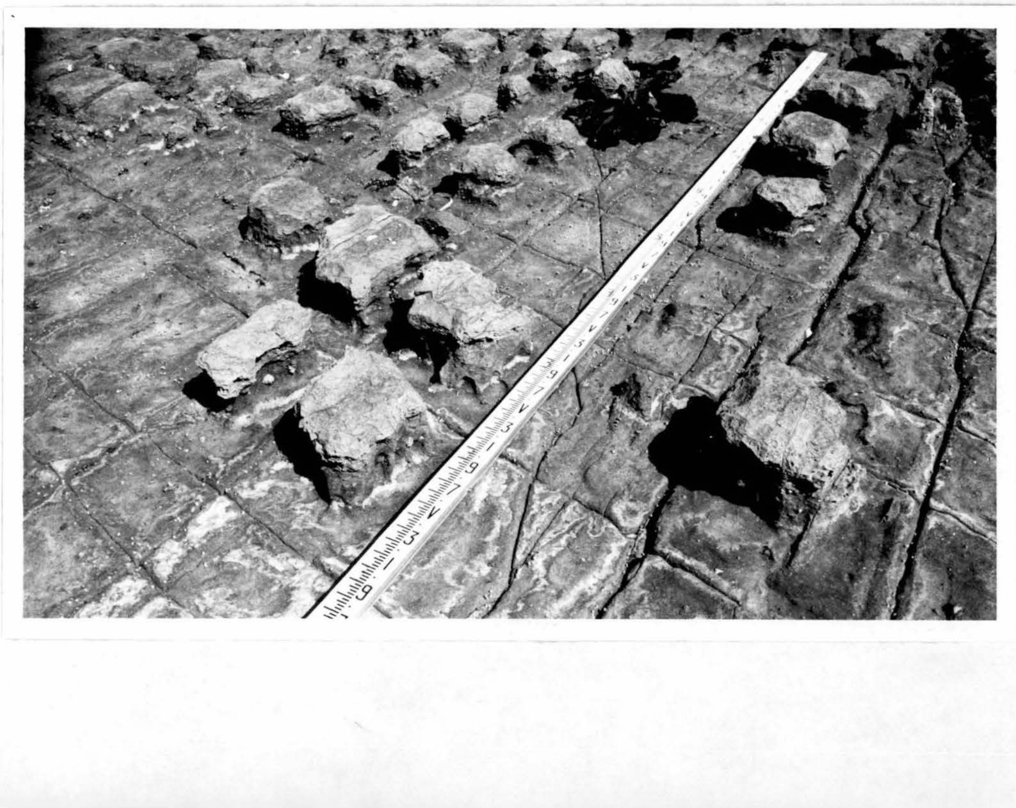
Photograph 3

Waffle Iron Platform. Surface on right half of photo is completely bevelled. Bevelling is incomplete in left half of photo.

Photograph 4

Remnant knobs on Waffle Iron Platform. Crystallized salt flanks the joints and occupies notches in the bases of the knobs. Small white spots on rock surface are the periwinkle *Melarapha unifasciata*.





It too is bevelled at about 2.0 feet msl, in its northwestern extremity. The surface then follows the dip slope to the southeast. The bed at lower elevations is divided into very regular rectangular blocks which are presently being quarried by wave action.

Wave Quarrying.

The entire edge of the Waffle Iron shows strong quarrying control, with angularity of outline the dominant feature. In one location, the southwestern corner of the upper bed, quarrying has stripped the weathering surface away to the top of the intermediate bed, leaving an arrowhead shaped channel 20 feet long and 10 feet wide at the widest point. The concept that quarrying is an active force at present was reinforced on June 5, 1966 when two blocks were observed lying on the remnant knob surface after having been hurled out of the channel. They were roughly rectangular, and each weighed about 100 pounds. One block was found 3.5 feet northwest of the head of the channel, while the other was 10 feet further along in the same direction. Although both blocks were perched on the tops of remnant knobs, the knobs themselves seemed to have survived the impact without major damage. The blocks continued to move towards the northwest (propelled by the southeasterly waves) in succeeding storms until on August 5, 1967 they were 30 and 35 feet away from the joint channel. Ultimately, they seem destined to join other quarried blocks in storage at the base of the cliff.

Weathering.

All the formative factors active on the Silver Gull platform also are present on the Waffle Iron. Weathering, both mechanical and chemical - with biological help, quarrying and some rock abrasion combined to form both platforms. Again, sub-aerial weathering was probably the most important feature in forming the present platform surface, followed closely by quarrying and other wave induced erosion.

Weathering is still very active on the Waffle Iron, as indicated by the remnant knobs. These features result from the rapid weathering of material in the vicinity of the joints, leaving the central areas of the blocks to be eroded more slowly as their sides and tops are removed. The morphology of this area seems to indicate a level of most efficient weathering, possibly related to the water table in the rock. The base level for weathering activity on the upper bed appears to be at 2.5 feet msl, 0.5 feet above the bevelled surface of the next lowest bed. This difference in base levels may be due to variation in permeability of the material comprising the two beds.

The fine sandstone of the upper bed is rapidly being removed to the 2.5 foot msl level in the vicinity of the joints and subsequently undergoing lateral weathering leaving horizontal areas surrounding the knobs. That removal of material is more effective at this level than at a higher location is indicated by the notch which is often present near the base of the knobs. The importance of lateral weathering can be seen in the very sharp angles between the tops and the sides of the remnant columns.

Other evidence for weathering on the Waffle Iron is the distinct horizontality of the surfaces of the two lower beds. In both instances, they are bevelled at heights of between 2 and 2.5 feet msl. The reason for the higher level of bevelling on the Waffle Iron, compared to the level on the Silver Gull platform, may be that the sandstones of the Waffle Iron are finer in grain than the rocks of the other platform, allowing a higher water table through capillarity. The common occurrence of standing water on the platform surface at the 2.5 foot level would suggest that the water table is not far below. As in the case of the Silver Gull platform, it is difficult to postulate any type of geologic explanation, inherent in the structure of the beds, to explain the bevelling effect. Weathering to a base level remains as the most likely explanation.

Organisms.

Biotic intertidal zonation on the Waffle Iron is quite similar to that occurring on the Silver Gull platform. Durvillea and lithothamnion are common below -1.5 feet; the coralline algae, limpets, chitons and other molluscs occur between -1.5 feet and mean sea level; and littorinids such as <u>Melarapha unifasciata</u> take over predominance from sea level to the highest point on the platform. No lichen zone exists on the Waffle Iron, not for lack of elevation, but because the location of the highest part is quite close to the edge of the platform where wave splash is sufficient to discourage even the hardy <u>Gasparinnia</u>.

<u>Future Development of Platform</u>.

Occasional quarrying and abrasion by wave action are the means by which the present Waffle Iron surface is most likely to be destroyed if sea level remains as at present. Before the existing platform is totally removed, however, weathering would have first bevelled the knobs off the upper bed. Ultimately, the quarrying which is so evident on the edges of the Waffle Iron would strip away all the present weathered beds, leaving a surface at the depth of the present offshore platforms, about -3.0 feet msl.

Formation of a new sub-aerial horizontal surface from the cliff behind the Waffle Iron would not be as rapid as would be the case with the Silver Gull platform. The cliff is bedrock, over twice as high as the cliff backing the Silver Gull platform, and vertical in places, requiring the removal of much more material for platform formation. Removal of weathered rock from the area would be made difficult by the energy absorbing collection of quarried boulders at the cliff base, which would also inhibit hydraulic action.

NUROO ISLAND

Nuroo Island, located 400 feet to the east of the Waffle Iron, is one of the most interesting shore features in the Eaglehawk Neck area. The island is roughly circular with a diameter of approximately 400 feet. The greatest height, 52.55 feet msl, occurs slightly west of the island center, with the western half of the island generally higher than the eastern half. A narrow joint channel, often dry at low tide, separates Nuroo Island from the mainland platforms to the north.

General Description.

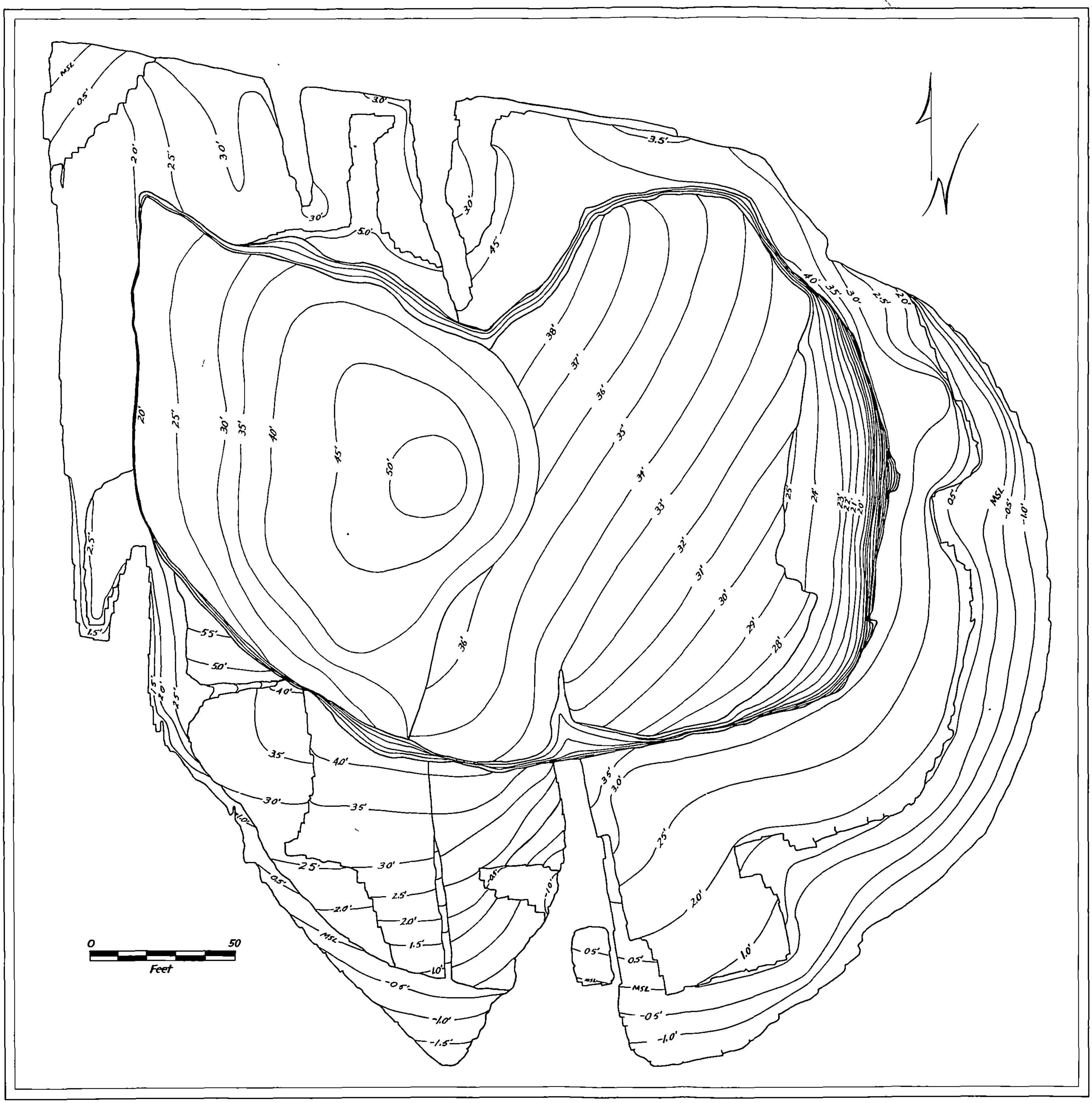
The island is almost surrounded by a fringing shore platform which varies in height from about 2.00 feet to 5.00 feet above mean sea level. Another platform, at a height which changes uniformly from 28 feet to 38 feet msl, forms the surface for most of the eastern half of the island. A cliff, which averages about 25 feet in height and is often vertical, rises from the lower platform to the upper platform and sloping island surface.

The portion of the island which does not support shore platforms occupies the higher elevations to the west. A soil cover has developed which has allowed a small grove of casuarina trees to gain a foothold. Other vegetation includes a sparse grass cover and profuse lichen on the surface of the upper platform, starting about 10 feet west of the cliff. Numerous bleached shells

Figure 5

CONTOUR MAP OF NUROO ISLAND

Beds have been bevelled horizontally to an elevation of 2.0 feet on the sheltered northwest side of the island. On the south and east, combined hydraulic action and weathering has caused some surfaces to be inclined seaward at angles differing from the dip.


0
50
Feet
MSL

on the island indicate former usage by aborigines, while modern man has left his mark in two small tombs containing human remains near the high point of the island.

Nuroo Island is formed of Permian sandstones and siltstones, with average bed thicknesses of ~~from~~ one to two feet. As elsewhere in the vicinity, bedding is well defined and jointing is pronounced. The beds strike N 33° E (033°) and have a dip direction of S 57° E (123°). Strike on the Nuroo Island beds is displaced 23° to the east compared with the Waffle Iron formations, while the dip of 4° is greater than that on any of the other features studied. The joint directions are not the same on all the Nuroo Island beds, but they do share the same intersector.

The platforms fringing Nuroo Island are broken by numerous joint channels. The largest channel, bearing N 25° W, passes completely beneath the center of the island and ultimately intersects the east-west channel that forms the island's northern boundary. Waves press continually beneath the island, quarrying a feature which is presently 30 feet deep and may in time become a well developed arch. Other less ambitious joint channels occur on the exposed southern and eastern platforms.

<u>Wave Activity.</u>

Nuroo Island receives more wave energy than any of the other platforms in the Eaglehawk Neck area. The island is completely exposed to the refracted southwest swell, sea breeze chop, and the high energy southeasterly storm waves. Kelp offshore may offer some slight protection, but the growth is not thick enough to be significant. Waves striking the platform range from the almost continuous 2 - 3 foot refracted southwesterly swell to the 25 foot storm waves generated by occasional southeasterly gales.

In contrast to the other platforms, depth of water offshore from Nuroo Island is sufficient to allow all but the biggest waves to proceed unbroken to the platform edge, a condition favoring clapotis. The east edge of the platform drops abruptly to -25 feet msl, while the south edge is the top of a cliff which descends to -15 feet msl. Offshore to the southeast the depth is -58 feet at a distance of 1000 feet.

Developmental Factors.

Nuroo Island features show strong evidence of weathering to a base level, in common with the platforms studied previously. However, much more of the Nuroo Island platform is above the level of high tide, compared to the lower platforms to the west. A situation also exists on Nuroo Island in which surfaces at the higher elevations are often quarried to the upper margin of a bed and the beds in lower areas are bevelled by weathering, completely the opposite to conditions prevailing on the other two platforms.

The main reasons for the difference are probably the island

Photograph 5

Aerial view of Nuroo Island. The boulders to the northwest of the island have been quarried and transported into storage by southeasterly wave action.

Photograph 6

East end of Nuroo Island undergoing wave attack. Such hydraulic action has caused the stepped profile on the eastern side of the island by quarrying of blocks.

configuration, the much greater wave energy available and the deep water offshore which allows waves to strike the platform edge before breaking. Because Nuroo Island has a high center, an immense amount of material would have to be removed by any mechanism which attempted to produce the profiles of the Silver Gull and Waffle Iron features. Greater wave energy raises the saturation level by increased height of wave splash, creating a higher base level for sub-aerial weathering than would exist in a more sheltered location such as occurs in the lee of the island. Deep water offshore lifts the effective level of quarrying by preserving the unbroken wave form until the platform surface itself is reached. The lower part of the wave undergoes clapotis, expending little energy on the vertical leading edge of the platform, while the upper part of the wave breaks at a higher elevation, inducing removal of the joint blocks.

The two effects, an increase in the height of weathering and quarrying base level, should diminish from east to west on the Nuroo Island south platform due to prevailing wave direction and shelter furnished by the reef offshore and Nuroo Island itself. The map shows a decrease in the height of platforms, from slightly modified dip slope features with maximum heights of 4 feet in the exposed locations to a bevelled, horizontal surface at slightly above 2.0 feet in the protected western area. This surface is about 120 feet long in the north-south direction and has an east-west extent of 25 feet. The surface in this entire area varies less than 0.2 feet in height. If it followed the dip slope, the surface would have shown a drop of 1.8 feet in the 25 foot horizontal distance in the direction of dip. Joints are flanked by 1/8 inch high ridges which impound the water which is common on the bevelled platform, even at low tide.

Other bevelled platforms flank Nuroo Island on its northern side. These features show the same characteristics as the western platform, except for their height of occurrence. The northern platforms drop from 4.5 feet to 2.0 feet with the surface continuity broken by two large joint channels. Wave splash also seems to offer the best explanation for the difference in level of these northern platforms. Waves racing down the east-west joint channel spill over onto the flanking platforms at progressively lower elevations as the water loses energy in its turbulent westward passage.

Hydraulic Activity.

The effects of hydraulic activity are very apparent on Nuroo Island. The eastern and southern platforms show the rectilinear plan form common to the wave-quarried beds on the Silver Gull and Waffle Iron features. In addition, the gross vertical profile in this area shows a stepped shaping of the leading edge of the platform due to quarrying through several beds simultaneously, in sharp contrast to the right-angle junction of submarine cliff and surface of the sheltered 2.0 foot western platform. The quarried blocks collect at the base of the submarine cliff or are pushed into storage in the area to the northwest of Nuroo Island (Photo 5). The several hundred large blocks present in this area attest to the occasional high energy of southeasterly waves. Hydraulic action may also be removing material by the abrasive effects of running water, possibly combined with cavitation. The rounded profiles on the eastern and southern sides of the island suggest that this may be the case.

The shape of the cliff and the type of junction with the surface of the platforms changes around the periphery of Nuroo Island. The cliff at the rear of the eastern platform slopes at an angle of about 70^{o} from the vertical and joins the platform surface in a curve with a radius of about two feet (Photo 7). No sign of a notch exists either here or on the southern platform, which has the same curved junction. Although the intersection curve is similar, the cliff backing the southern platform is vertical and even overhanging in places.

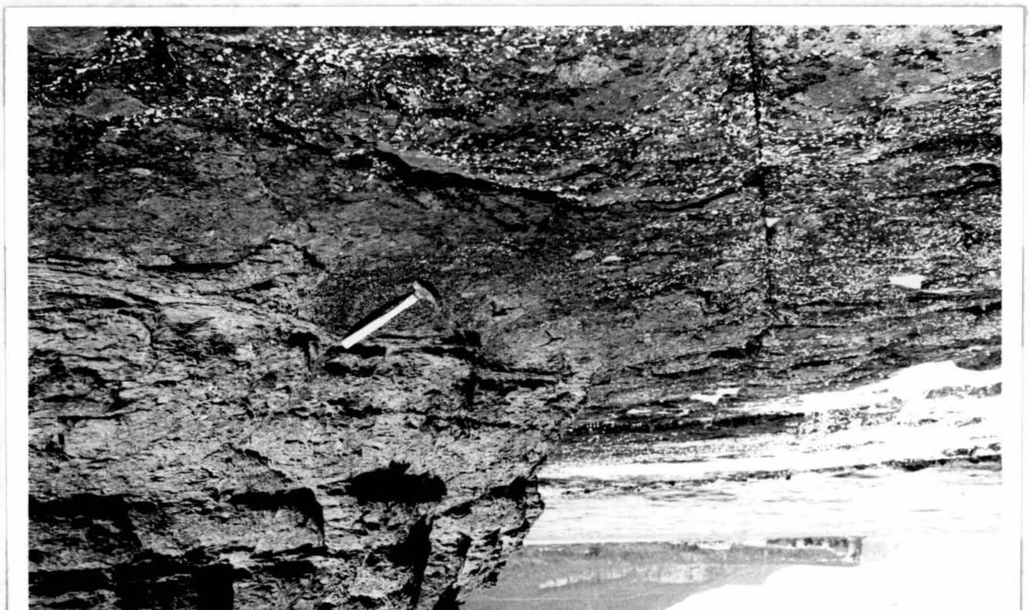
The only notching present on Nuroo Island occurs at the junction of the western platform surface and the attendant cliff (Photo 8). The cliff in this case is vertical or slightly overhanging and has a notch about one foot deep at its base. The

Photograph 7

Exposed, eastern side of Nuroo Island. The platform is sloping and notching is not prominent.

Photograph 8

Sheltered, western side of Nuroo Island. The platform is horizontal and a large notch occurs at the base of the overhanging cliff.



presence or absence of notching on Nuroo Island seems to be dependent on the type of activity dominant in platform formation. The notch is present where weathering is most active and absent where quarrying is the most important factor.

Elevated Surface.

A very prominent feature of Nuroo Island is the elevated, sloping rock surface extending eastward from the island center. This surface is roughly rectangular with dimensions of about 210 feet in a north-south direction and 100 feet in east-west extent. It rises from 28 feet msl in the southeast, steadily up the dip slope to 38 feet msl in the northwest. A stepped profile, apparently the result of quarrying, occurs on the eastward edge of the surface, while a simpler angular junction with the descending cliffs takes place on the north and south. The western edge is covered with soil where it encounters higher ground.

This elevated platform is not now in the process of formation. A heavy lichen cover indicates that most of the surface is not being abraded or quarried at present. Weathering is taking place, with many pits in evidence, but this activity is degrading the surface regularity. Some present wave quarrying, also reducing the uniformity of surface, is likely on the eastern edge where the profile is stepped through several beds and lichen is absent.

With degradation of the platform at present, the surface could have been created by wave stripping in the past by a higher level of quarrying, through a marked increase in storminess, a rise in relative sea level, or both. An increase in storminess sufficient to cause extensive quarrying at that elevation would be difficult to imagine, however, as waves would need to have been over 50 feet high to accomplish the work. It is more likely that the platform is a relict feature, created either during an ancient higher stand of the sea or elevated by local crustal movement associated with the faulting and folding in the area.

Organisms.

Biological zonation is slightly different on Nuroo Island from that encountered on the Waffle Iron and Silver Gull platforms. The island's greater height and more exposed position both add new life zones and change the levels of occurrence of the previously listed communities. Lichen, found only in small patches on the highest part of the Silver Gull platform, is very profusely present on the upper platform at a height of from 28 to 38 feet. Above this level, a zone of grass and tree growth continues to the 52 foot summit.

The littorinid zone is extended for about 7 feet higher than on the other platforms. The most obvious reason is that the other platforms did not reach this height, but the increased wave splash also allows the periwinkles to exist at higher levels. Wave splash does not seem to have noticeably affected the distribution of the lower zones, however, and they have approximately the same elevations as on the other features. The sheltered western platform on Nuroo Island shows the characteristics of zonation similar to the Waffle Iron and Silver Gull platforms.

Future Development of Platform.

If sea level stayed at the present height, Nuroo Island would ultimately take the form of the reef to the east. The upper surface would be located at about -5.0 feet msl, which appears to be close to the quarrying base level in this area. Before that happened however, the island would first form an arch and later two stacks as the north-south joint channel enlarged. During this interval, sub-aerial weathering and quarrying would be reducing the tops and sides of the island, leaving a surface which would be either at weathering base level or quarrying base level, depending on the comparative efficiency of the two agencies. If weathering were the more active, the wave splashed surface would be higher than the 2.0 foot level now found in the shelter of the island. However, this condition would be transitory until the quarrying base level was eventually reached at an even lower elevation.

SUBMARINE PLATFORMS

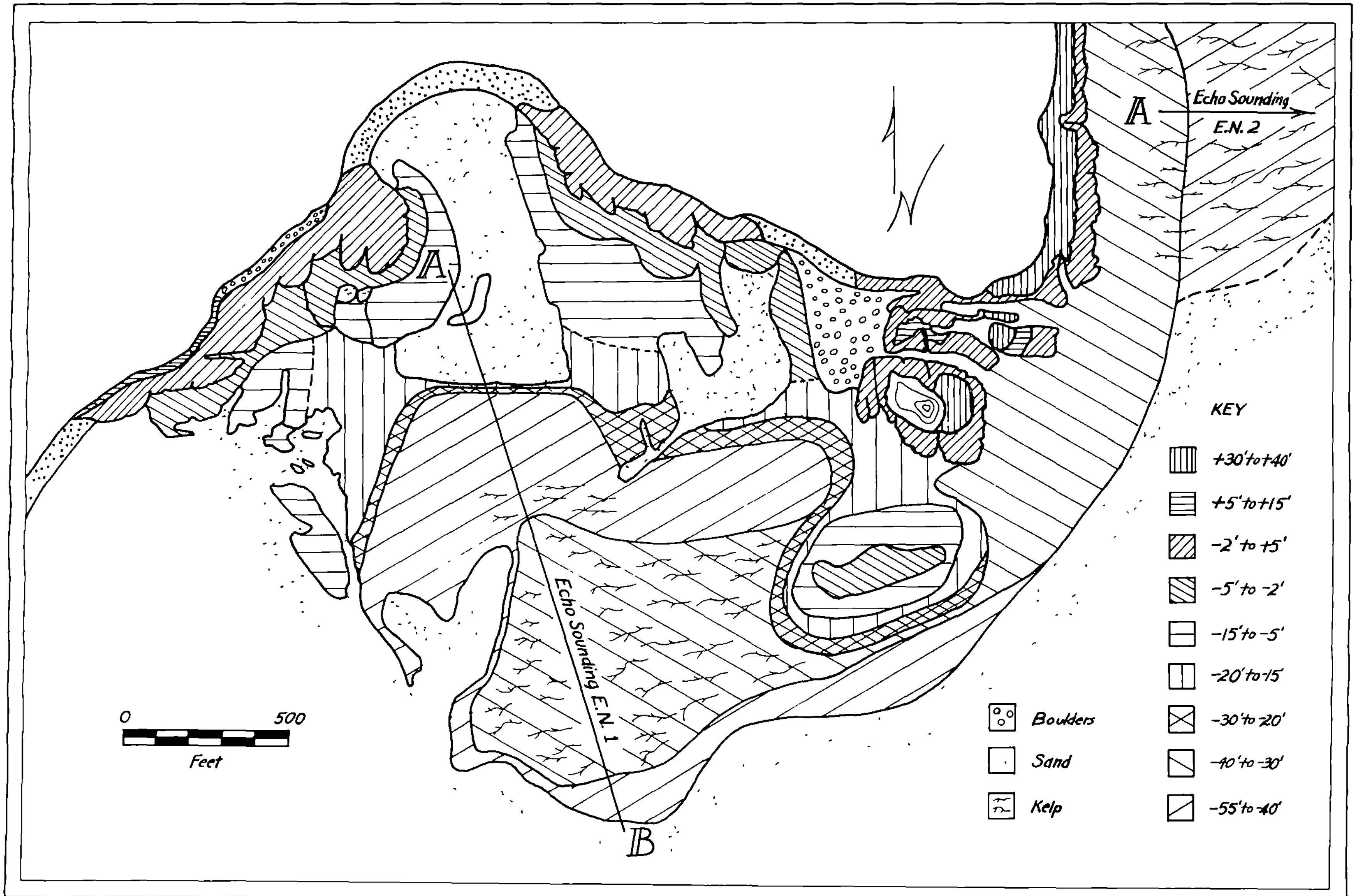
Submarine platforms in the northern bight of Pirate's Bay are far more extensive than their sub-aerial counterparts. Rock platforms occur in an area extending for a distance of 1500 feet south of the Silver Gull platform and about 1500 feet in an east-west direction. However, not all the area offshore consists of rock platforms. A considerable amount of sand is evident between platforms and sand surrounds the outer edge of all the submerged platforms at an average depth of 44 feet. Within the platform zone, the sand generally occupies areas weakened by faulting or folding. The greatest expanse of sand, a strip about 700 feet long and 200 feet wide between the Silver Gull and Waffle Iron platforms is the expression of the anticlinal axis. Another area of sand to the east, approximately 450 feet by 150 feet, is in a shatter zone associated with a fault near the Waffle Iron.

Elevational Characteristics.

The Eaglehawk Neck platforms, both sub-aerial and submarine, can be classified into elevational groupings (Figure 6). Sub-aerial platforms occur in zones from -2 to +5 feet, +5 to +15 feet, and +30 to +40 feet. Submarine platforms range downward from -2 to -5 feet, -5 to -15 feet, -15 to -20 feet, -20 to -30 feet, -30 to -40 feet and -40 feet to -55 feet. Some surfaces exist outside these zones, but their areas are not extensive.

Figure 6

ELEVATIONAL GROUPINGS OF EAGLEHAWK NECK PLATFORMS


A
Echo Sounding
E.N. 2
N
A
Echo Sounding E.N. 1
B
0
500
Feet
KEY
+30' to +40'
+5' to +15'
-2' to +5'
-5' to -2'
-15' to -5'
-20' to -15'
-30' to -20'
-40' to -30'
-55' to -40'
Boulders
Sand
Kelp

Sub-aerial and shallow water submarine platforms generally show elevation differences of about 5 feet or less between surfaces, while features in deeper water often show a 10 foot spacing. Limited vision inherent in underwater exploration might account for the variation in spacings, with the deep water features being inaccurately described, but echo soundings also indicate the gross 10 foot level differential. The seaward edges of the submarine platforms are usually vertical. Occasionally, large quarried blocks lie at the bases of the submarine slopes.

All of the sub-aerial platforms with the exception of Nuroo Island are flanked on their seaward limits by a platform at 2 to 5 feet below mean sea level. At the present time even the lowest tides fail to expose the surface of this platform to sub-aerial conditions. Seaward of the -5 foot feature is an extensive platform at a depth of -10 to -12 feet. This surface is far larger than the -5 foot platform and covers more area than any of the terrestrial platforms. Fringing the -10 foot platform in some locations is a feature at -17 to -20 feet. The -20 foot surface occurs in limited positions flanking the axis of the anticline and in the vicinity of Nuroo Island, where it is the first submarine level encountered on the island's southwestern side.

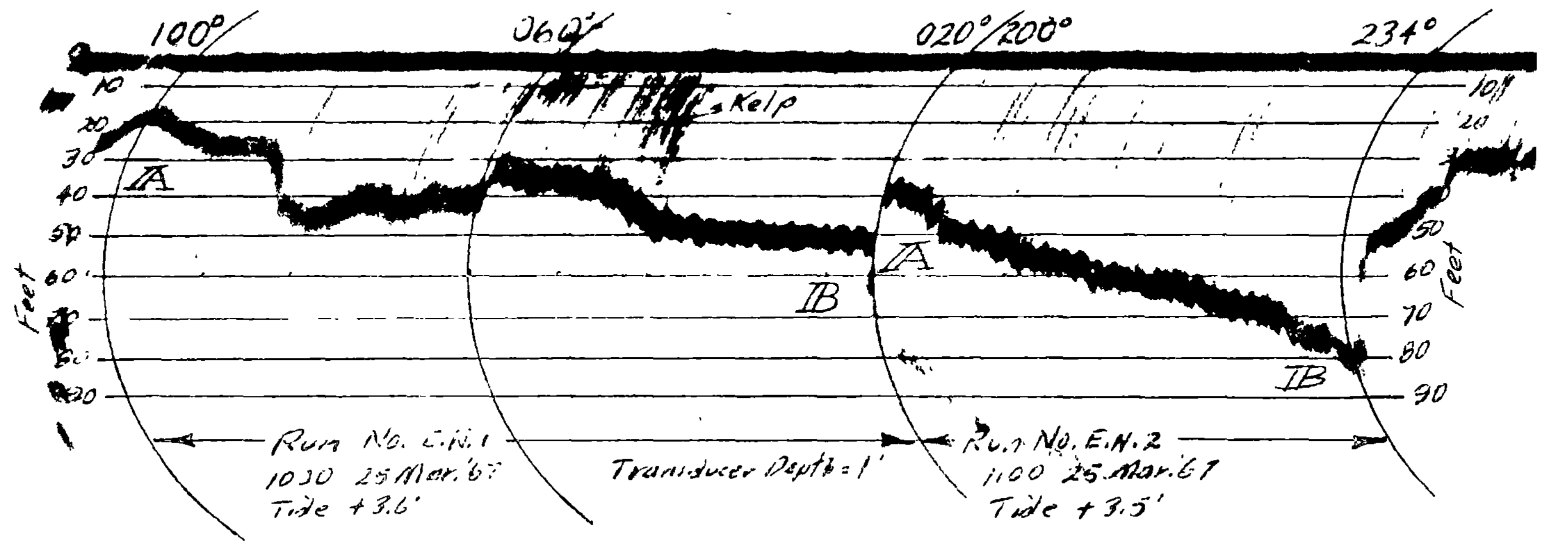
Depths drop abruptly seaward from the -20 foot platform to -40 feet, the deepest portion of the central area. The -40 foot platform forms a shallow, flat-floored valley running east and west between Nuroo Island and a point 500 feet off the Tessellated Pavement. It is similar in morphology to the area between Nuroo Island and the mainland. Elevations rise seaward where an extensive platform at -30 feet is located. This platform has the largest surface area of any in the region, terrestrial or sub-marine, having dimensions of 600 feet in the north-south direction and 800 feet on the east-west axis. The southeastern edge of the platform seems to slope gently to another level at about -35 feet, but sounding is difficult in this area due to heavy kelp cover. Still further seaward is a fringing platform at the same depth as the central feature, -40 feet.

To the east of the great mass of the -30 foot platform is a reef which rises to within 5 feet of mean sea level. The reef is composed of platforms at three levels: one at -5 feet, 200 feet by 100 feet in extent; one at -12 to -15 feet which is 300 feet by 200 feet; and another at -20 feet. The -20 foot platform extends to the southeastern edge of Nuroo Island where it forms the base of the submarine cliff.

Off the north end of Nuroo Island lies another extensive series of platforms which extend seaward from the high cliffs in that area. These platforms also descend in steps, starting from a depth of -30 feet immediately seaward from the terrestrial platform. The -30 foot platform drops to -35 feet 100 feet offshore where the -35 to -40 foot platform extends for 200 feet. At this

Figure 7

EAGLEHAWK NECK ECHO SOUNDINGS


100°
060°
020°/200°
234°
Kelp
Feet
Feet
Run No. E.N.1
1030 25 Mar.'67
Tide +3.6'
Transducer Depth = 1'
Run No. E.N.2
1100 25 Mar.'67
Tide +3.5'

point the surface drops to -48 feet for 100 feet horizontally and then descends to -52 feet for another 300 feet. Another jump occurs at the seaward edge of the -52 foot platform where sand is encountered at -58 feet.

Submarine Platform Morphology.

The submarine platforms vary little in morphology from their sub-aerial counterparts. The surfaces are fairly level and show the pronounced jointing evident on the sub-aerial platforms. Joints on the surfaces of the submarine platforms are almost always depressed below the surrounding blocks. These depressed joints show characteristics similar to those found on rocks comprising the Silver Gull and Waffle Iron platforms below 2 feet msl. Because, on these platforms, the saturation level appears to be near 2 feet msl, the surfaces of both the lower sub-aerial platforms and the submarine platforms are constantly wet with water. The spheroidal tendency of the joint blocks might then be related to the spheroidal weathering encountered in rocks saturated by a ground water table. It is difficult to say whether joint depression on the submarine platform surface occurred sub-aerially or in the submerged position. Either ~~could be~~ is possible, although, as the lower elevations of the sub-aerial platforms presently show this form, the shaping could have occurred as sea level rose. Whatever the cause, all of the joints on submarine platforms were either flush with the platform surface or depressed, none were flanked by ridges as is the case on many horizontally bevelled sub-aerial platforms (for instance the Tessellated Pavement, Chapter 17).

Leading edges of some of the submarine platforms are composed of blocks with rounded faces, with a pronounced re-entrant above the lower bed. (Photo 9). Often the platforms show the rectilinear overall outline which indicates quarrying action along the joint planes. Some rocks derived from quarrying, varying in size from large cobbles to boulders, are present on the platform surfaces, usually at the base of the cliff leading to the next highest level. These rocks are normally covered with marine growth and lie in positions which indicate that they are not often disturbed.

Organisms.

The platforms in general are matted with marine organisms. Many types of algae combine to envelop the surfaces with coralline and non-coralline cover. The coralline algae forms a continuous coating, while the non-coralline types, such as *Durvillea* in shallow water and *Macrocystus* in deeper areas provide a less continuous cover. The effect of the algae is to both inhibit the movement of tool stones which were attempting to abrade the surface and to cushion the surface from impact if any rocks did actually succeed in moving across the platform. However, kelp occasionally erodes the platform surface mechanically itself by plucking rocks, firmly attached to holdfasts, during periods of high wave energy. Erosion

Photograph 9

Edge of bed forming Submarine Platform at -4 feet, msl. Tool stones are absent and algal coating is not disturbed.

Photograph 10

Surface of Submarine Platform at -4 feet msl. Area surrounding joints is lower than the block centers.

may also take place by the chemical and mechanical action of the algal coating.

Animals as well as vegetation forms are prominent on the surfaces of the submarine platforms. Great fields of turban shells inhabit the shallow water surfaces, furnishing protection from abrasion, but possibly subjecting the rock to biological erosion. Other molluscs are present, such as the abalone (Haliotis) which may also cause erosion through scraping the surface in the removal of algal food and by chemical solution. The gently rounded appearance of the underwater blocks could be at least partially the result of this biologically instituted erosion, which would have no base level.

Rock Abrasion.

Submarine inspection yields little support for rock abrasion as an underwater erosive force. Some quarrying may take place during large storms, but the blocks are apparently moved into storage fairly rapidly and do not grind back and forth repeatedly on the platform surface. The occurrence of such quarrying must be fairly rare because no trace could be found of a disturbance in plant and animal life which would indicate the movement of rocks across the surface.

Lack of Evidence for Development or Modification at Present.

With so little evidence for active quarrying, rock abrasion or any other rapid shaping force, submarine platforms below -5 feet msl appear to be undergoing very little modification at present.

Quarrying is increasing the size of the -5 foot platform, at the expense of the sub-aerial features, and may also be planing the top of the offshore reef. However field study and wave tank results (see Chapter 15) suggest that it is unlikely that quarrying is now taking place at depths much greater than -5 feet in this area. Because the more deeply submerged platforms are not at present in positions favorable for platform production, they must be relict features produced during times of previous lower sea levels. Barring uplift, the fate of these submarine features will be an inexorable wearing away of rock surfaces through biological, chemical and biochemical agencies, possibly to the extent of degrading the overall platform morphology.

Chapter 4

KANGAROO BLUFF

A number of platforms in the Permian sandstones and siltstones of southeastern Tasmania share the same general characteristics shown on the Eaglehawk Neck features. Several such platforms occur at Bellerive, about a mile eastward across the Derwent estuary from the center of Hobart. One of the most interesting of the Bellerive platforms is located at the foot of Kangaroo Bluff, south of the town center.

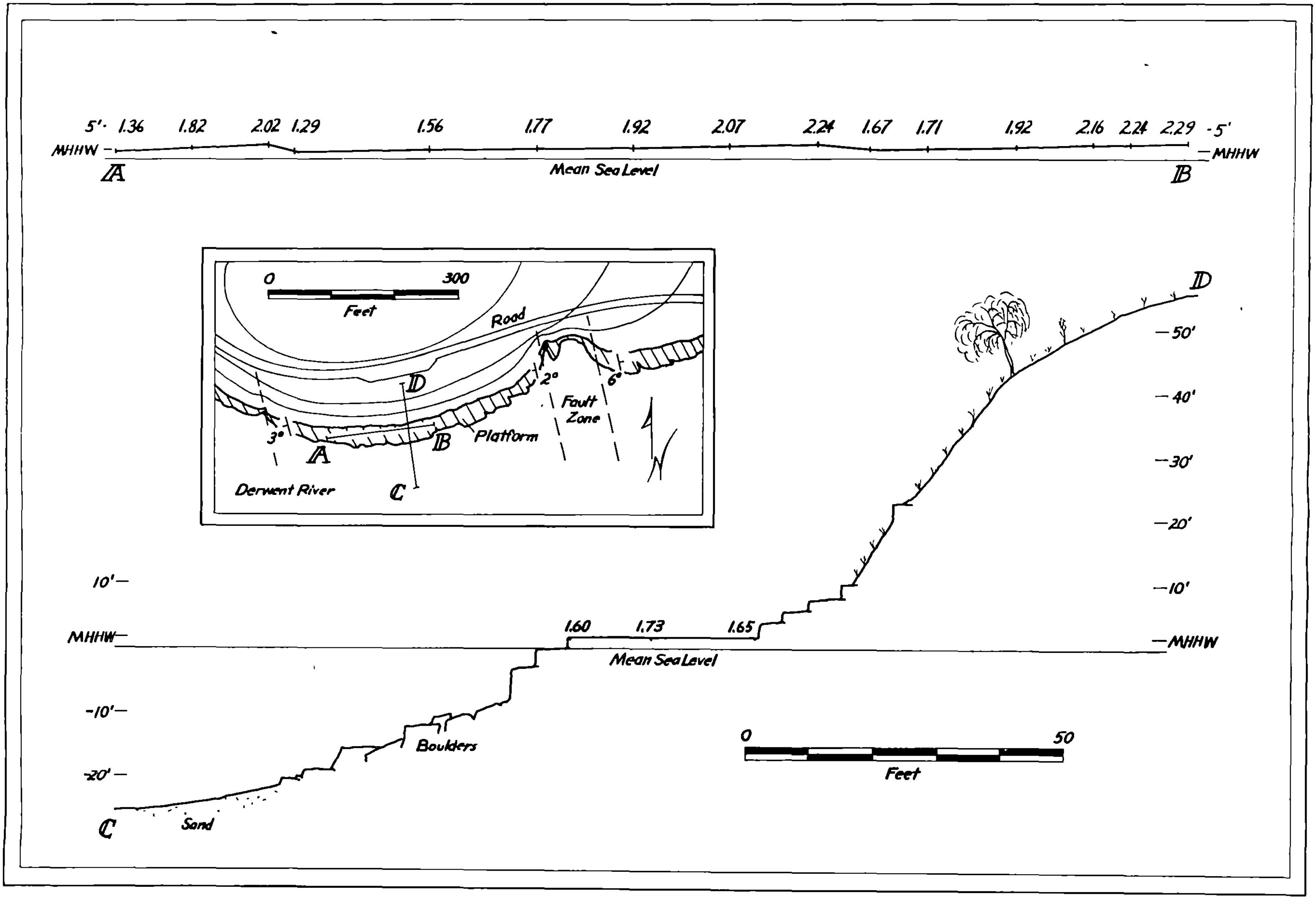
STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

The Kangaroo Bluff platform is a fairly narrow feature, compared to the Eaglehawk Neck structures, but has a similar length. The main terrestrial platform exposed at high tide, averages about 25 feet in north-south width over a total length of 420 feet. The platform surface is bounded on the north by shelves backed by a steep cliff, with occasional soil cover and vegetation, and on the south by a stepped profile leading to a submerged boulder bed. Western and eastern boundaries are formed by fault zones from which the rock has been quarried, leading channels to the base of the cliff.

Kangaroo Bluff is composed of well bedded Permian siltstones with average bed thicknesses of about 18 inches. Jointing is

Figure 8

KANGAROO BLUFF PROFILES


5'
1.36
1.82
2.02
1.29
1.56
1.77
1.92
2.07
2.24
1.67
1.71
1.92
2.16
2.24
2.29
5'
MHHW
MHHW
A
Mean Sea Level
B
0
300
Feet
Road
D
2°
6°
Fault Zone
3°
A
B
Platform
Derwent River
C
D
50'
40'
30'
20'
10'
10'
MHHW
1.60
1.73
1.65
MHHW
Mean Sea Level
-10'
Boulders
0
50
Feet
-20'
C
Sand

prominent, but does not exhibit the marked regularity of the Eaglehawk Neck beds. Limonite fills most of the joints, often leaving a remnant ridge when the siltstone surface is lowered.

Overall geologic structure at Kangaroo Bluff is a faulted monocline with one limb comprising the entire platform and the fault forming the eastern boundary. Strike of the beds is N 30° W (150°) which remains constant over the entire extent of the platform. To the west of the fault, the dip direction, S 60° W (240°) is also constant, running parallel to the long axis of the platform from east to west. The dip angle changes slightly over this distance from 3° on the west to 2° near the fault zone. East of the fault zone the dip is N 60° E at an angle of 6°.

CLIMATE

Atmospheric conditions at Kangaroo Bluff are not markedly different from those at Eaglehawk Neck. Precipitation is less, with an average of 26.4 inches annually at Hobart, but the temperatures are about the same with an average of 62° in January and 46° in July. As at Eaglehawk Neck, frosts are neither prevalent nor severe. Kangaroo Bluff is subjected to a strong southeasterly sea breeze which often reaches strengths of 20 knots in the summer months. The bluff is not exposed to the strongest winds in the area, the northwesterlies, which have been recorded at 92 knots. However, southerly storms, with winds of up to about 40 knots, can sweep almost unhindered up the estuary.

WAVE CHARACTERISTICS

Three general types of waves strike Kangaroo Bluff. The most common is the southwesterly swell refracted around the coast of Tasmania and into the Derwent Estuary. By the time the swell reaches Bellerive, little energy is left and heights seldom are greater than about 3 feet. On the summer afternoons, the sea breeze often creates a chop of approximately the same height which masks the swell. Strong storm conditions, mostly in the winter months, can cause the highest waves of all, with heights of about 6 or 7 feet possible over the 10 to 15 mile fetch to the south.

TIDAL REGIME

Tides at Kangaroo Bluff are probably similar to those listed in the Admiralty Tide Tables for Hobart, across the estuary. With $F = 1.43$, the tidal curve is mixed, predominantly semidiurnal, but with a strong diurnal component. Mean higher high water is 4.7 feet, mean lower high water is 3.8 feet, mean higher low water is 3.1 feet and mean lower low water is 1.7 feet. Mean range between higher high water and lower low water is 3.0 feet, giving a value for mean sea level of 3.2 feet ($4.7 - 1.5 = 3.2$), based on a Cape Horn datum. The Marine Board of Hobart has some doubts about the accuracy of the predicted values, however, as their tide gauge data gives an actual mean sea level at 4.17 feet

Hobart datum or 3.97 feet Cape Horn datum. These figures are 0.77 feet higher than the predicted values, possibly because of raised levels due to fresh water flowing from the Derwent River. For purposes of platform study, the tide gauge data was adopted.

THE PLATFORM

The Kangaroo Bluff platform shows evidence of the activity of both terrestrial and marine erosive forces. Sub-aerial erosion is quite active on Kangaroo Bluff at all levels from about 1.6 feet msl to the top of the bluff 35 feet higher. This is illustrated in the upper levels by the generally sloping nature of the cliff and in the lower areas by the presence of shelves at the cliff base. The shelves, at intervals equalling the bed thickness of about 18 inches, extend to heights of about 5 or 6 feet above the platform and are topped by small elevated platforms a few feet in width. No "wave-cut notches" occur either at the rear of the shelves or the platform itself.

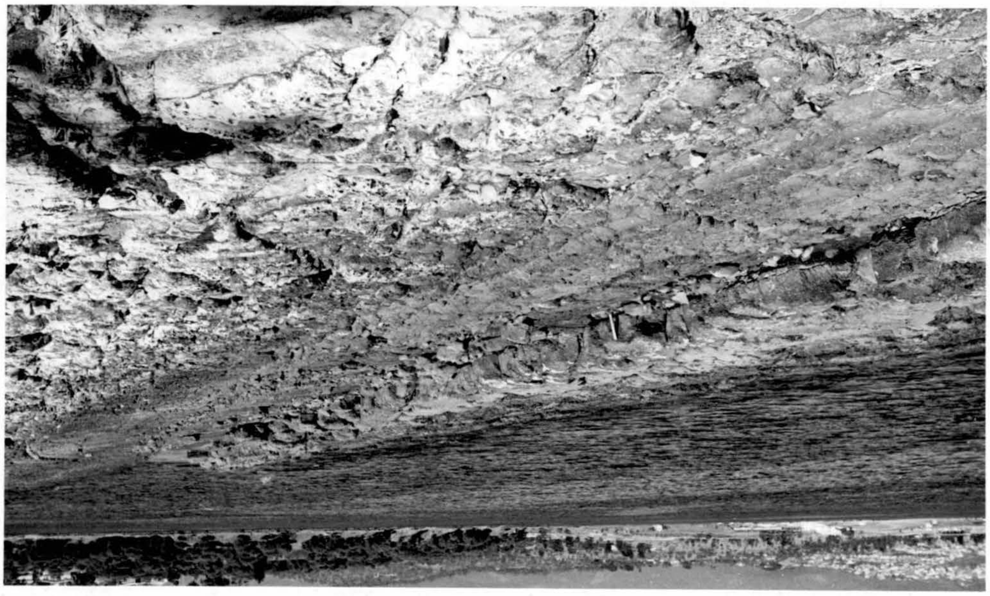
The major part of the platform has been formed by a combination of weathering and quarrying. Weathering has occurred to an approximate 1.6 foot msl base level where some of the gently dipping beds are bevelled. More often however, quarrying has stripped the weathering-weakened beds to a level below the saturation height, resulting in a cuesta type morphology with the ridges slightly above saturation base level and the valleys a few inches below.

Photograph 11

Kangaroo Bluff Platform. The geology pick is leaning against one of the "cuestas".

Photograph 12

Weathering control over quarrying. The platform is 100 yards north of the Kangaroo Bluff platform. Quarrying has taken place where weathering in joints and along the bedding plane has loosened the blocks.



(Photos 11 and 12). Quarrying does not seem active enough to strip material at lower elevations except at the leading edge of the platform where as many as three beds have been removed in producing the stepped profile.

Weathering and Rock Abrasion.

Evidence for weathering includes both the bevelling of the beds and the deep pitting present on some of the slightly higher platform and shelf surfaces. The pitting is hemispherical in shape and reaches depths of 2 inches, although the average depths are closer to 3/4 inch. A few pan areas, surrounded by joints with attendant ridges, occur on the platform surface. The pans often contain sheets of water, impounded by the ridges and jutting sheets of limonite in and near the joints. In terms of total area, the pans occupy only a small portion of the platform surface. Much of the platform appears to be at or below the base level of weathering and pits and pans are not numerous. Many of the pits that are present could have been formed by biological action in the past. As at Eaglehawk Neck, joints become increasingly depressed seaward on the platform surface.

In no instance can rock abrasion be shown to be a significant factor in the formation of the Kangaroo Bluff platform. Very few loose rocks are present on the platform surface and the fragile raised limonite ridges in the joints crisscrossing the platform indicate that movement of rock across the surface is rare. Most of the quarried material is either stored in joint channels at the ends of the platform or are located at the base of the seaward cliff at a depth of about -8 feet.

Offshore Profile.

The offshore profile of Kangaroo Bluff shows three basic zones. The profile from sea level to about -3 feet reflects active wave quarrying in the stepped outline created by the successive stripping of beds. A cliff occurs at -3 feet which drops to a boulder bed at -8 feet. The boulders are large, some reaching dimensions of about 3 feet long, 3 feet wide and 1.5 feet thick, and are very angular. They do not appear to have moved far from the locations where they came to rest after being quarried. The boulder bed slopes southward for about 40 feet where it ends at a depth of -20 feet. From this point a sand, convex upward surface drops to a depth of 80 feet about 1000 feet to the south.

Organisms.

Although in the past, biological activity on Kangaroo Bluff may have had some similarity with that of Eaglehawk Neck, at present marked differences occur. The terrestrial zones containing casuarina trees and lichen compare with Nuroo Island conditions, but the intertidal zones are quite different. There is a complete absence of bull kelp (Durvillea), chitons and limpets. Local fishermen state that pollution may have now made the area uninhabitable for many species which were formerly abundant. In support of this view, Admiralty Chart 105 which was drawn in 1863 shows extensive kelp beds off Kangaroo Bluff.

A few species seem to be thriving, however, and a high concentration of small barnacles, Chamaesipho columna, attests to their adaptability. Large numbers of blue starfish (Patiriella calcar) are also prominent in the lower mid littoral zone. Pits from which the chitons and limpets sally forth in their grazing on other platforms are inhabited at Langaroo Bluff chiefly by a reduced number of periwinkles, mostly Melarapha unifasciata. It is possible that the pits date back to the time before the chitons and limpets were killed by effluents.

Future Development of Platform.

The future of the Kangaroo Bluff platform, if sea level remains as at present and storm conditions do not change, is for a continuation of the gross platform morphology with widening of the total width through creation of more extensive quarried platform at -2 to -4 feet and a larger sub-aerial platform at between 1.5 feet and 2 feet. Sub-aerial weathering will keep reducing the rock to a level where hydraulic activity, such as water hammer and compression of air in joints, can strip the beds in forming the cuesta pattern in the direction of dip. Meanwhile, hydraulic and biological forces will be slowly removing the seaward beds at the expense of the present exposed cuesta platform. If sub-aerial weathering were to stop, marine action would eventually destroy the present sub-aerial platform and proceed to the base of the bluff. As cessation of weathering is unlikely, however, the surface will keep being formed from the bluff as the platform's seaward edge is quarried.

Chapter 5

CAPE GRIM PLATFORMS

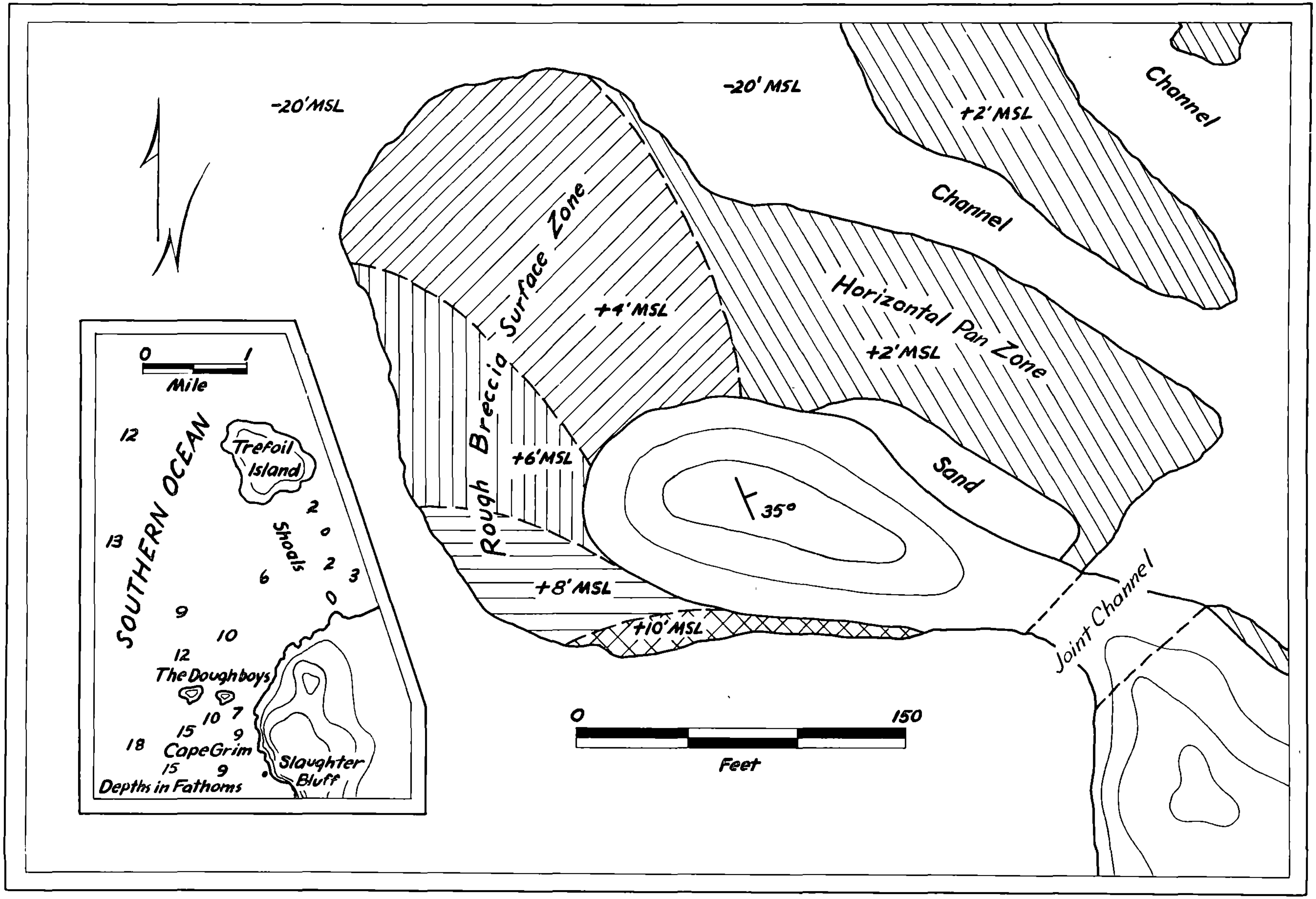
Platforms having horizontal, uniform surfaces at levels at or slightly above high tide occur in other rock types than the Permian formations of southeastern Tasmania. Tertiary Basalts on the north coast of the island have profiles and relative elevations similar to the southeastern features, even though located in different wave and tide regimes.

The Cape Grim area, on the extreme northwestern tip of Tasmania 200 miles northwest of Hobart, contains many good examples of Tertiary Basalt platforms. Unfortunately, they are very difficult of access. The platforms are generally at the foot of fairly steep cliffs, several hundred feet high. Good platforms also occur on islands offshore, but currents are strong in the channels and navigation is hazardous.

Because of the many difficulties, field work in the Cape Grim area was not as detailed as that at Eaglehawk Neck. The tide gauge was not installed and surveying was limited to measurement by Brunton Pocket Transit. The Cape Grim platforms are included here for the information yielded in the study of their gross morphology, in spite of the less precise data.

Figure 9

MAP OF SLAUGHTER BLUFF PLATFORM


-20'MSL
-20' MSL
Channel
+2' MSL
Channel
Rough Breccia Surface Zone
+4' MSL
Horizontal Pan Zone
+2' MSL
+6' MSL
Sand
35°
+8' MSL
+10' MSL
Joint Channel
0
150
Feet
0
1
Mile
SOUTHERN OCEAN
Trefoil Island
12
13
Shoals
2
0
2
3
6
0
9
10
12
The Doughboys
10
7
15
9
18
Cape Grim
15
9
Slaughter Bluff
Depths in Fathoms

STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

The basalts of northern Tasmania, including the Cape Grim rocks, emanated from volcanic centers during the Tertiary. The Cape Grim basaltic volcanics have buried beds of Precambrian quartzites to depths of at least 200 feet. Recent studies indicate that the main source for the olivine basalts of Cape Grim was to the south of the Doughboys, two small islands about one-half mile offshore, to the west. The dip of the Cape Grim volcanics, about 35° at an azimuth of 70°, would support this thesis.

Pillow brecias are the most prevalent igneous rock type in the Cape Grim area. This black glass basalt has been given the name "Slaughter Bluff Volcanic Breccia" by Sutherland and Corbett (1967) who suggest that the flows were the result of submarine eruptions. Although "bedding" is fairly well pronounced, jointing is not prominent and the pillows are extremely brecciated. Tuff also occurs in limited locations on the Cape Grim coast.

In addition to the basalts and quartzites, the Cape Grim area also contains aeolianite deposits near the bases of the westward facing cliffs. The aeolianite is probably Quaternary in age and is usually perched about one quarter of the way up the basalt cliffs from present sea level.

Cape Grim and the adjacent coastline are the seaward edges of a basalt surface which lies at an elevation of about 200 feet above sea level. The surface is undulating and loses elevation to the east. Cliffs on the western margin generally slope at an angle of about 40° from the horizontal for about three-quarters of their height, and then plunge vertically to sea level where platforms often join the base of the cliff. Some of the headlands are tipped with stacks and reefs, exposed at high tide.

Because no underwater exploration was carried out in the locality, little information can be included on submarine topography. Admiralty Chart 3687 depicts the area, but soundings are few in the area of interest. The chart shows depths of 7 and 9 fathoms about one-quarter mile offshore and 15 fathoms a half mile further west. From examination of breaking waves, depth immediately off the platform is probably about 25 feet. Vertical cliffs, supporting Durvillea, plunge to this level from the platform surfaces. Several reefs, constantly awash, occur about one hundred yards offshore from Slaughter Bluff. The reefs probably represent recently truncated stacks which are now slowly being reduced by hydraulic action.

CLIMATE

The general climate of the Cape Grim area does not differ greatly from that of Eaglehawk Neck. Average annual rainfall is about 40 inches, mean temperature for January is close to 60° and the mean temperature for July is about 48°. Wind directions do contrast, however, with the Cape Grim winds showing a marked westerly tendency throughout the year at all times of day. The sea breeze is an important component of the Cape Grim wind pattern as it blows on many summer afternoons from the northwest.

WAVE CHARACTERISTICS

Waves striking the Cape Grim coast are also quite different from those of Eaglehawk Neck. Cape Grim is exposed to the full impact of the southwest swell which has been generated in the higher latitudes of the southern hemisphere. The swell is almost constant and regularly pounds the coast with waves about eight feet high. The swell can reach heights of 15 feet or more, increasing as storms add energy. A figure for the maximum heights attained by storm waves in this area is only a guess, based on information from fishermen, but would probably be about 30 feet except for rare, phenomenal gales.

TIDAL REGIME

Tides have apparently never been measured in the Cape Grim area, but data in the Admiralty Tide Tables for stations to the east and south give some idea of their values. Burnie, 70 miles to the east on Bass Strait, has tides which are near the borderline between semidiurnal and mixed semidiurnal, with $\frac{K_1 + O_1}{M_2 + S_2} = 0.238$

Stanley, also on Bass Strait, 30 miles east of Cape Grim, has data listed on heights, but no harmonic constants. Mean values for Stanley are high water springs; 8.8 feet, high water neaps; 8.0 feet, low water springs; 2.2 feet, low water neaps; 3.0 feet; yielding a spring tide range of 6.6 feet. Closest station to the south of Cape Grim is Pieman River, 70 miles away. With $\frac{K_1 + O_1}{M_2 + S_2} = 1.32$, Pieman River tides have a mixed, predominantly semidiurnal form, although the semidiurnal quality is not pronounced. The average range here, 2.2 feet, is far less than on Bass Strait as higher high water is 3.0 feet, lower high water is 2.0 feet, higher low water is 1.9 feet and lower low water is 0.8 feet. Spring tide range would be a little less, about 2.0 feet, although no figures are given.

Cape Grim tides probably have more characteristics in common with Pieman River than Bass Strait because of the west coast location of the cape and the shallow water and islands separating it from Stanley. Tides at Cape Grim could thus be mixed, predominantly semidiurnal in form, with an average spring tide range of about 3.0 feet and an average higher high water - lower low water range of 3.3 feet.

THE PLATFORMS

The platforms in the Cape Grim area are generally best developed on the north and northeast sides of points and islands. Profiles exposed to the southwest, the direction of high energy swell and wave attack, show narrower platforms which slope distinctly seaward. One platform which indicates this phenomenon is located about 2000 feet south of Cape Grim, near Slaughter Bluff.

The Slaughter Bluff platform fringes a point which is being separated from the mainland by erosion in a probable joint (Photo 13). The platform is crescentic in shape and measures about 420 feet in extreme length. Width varies from 30 feet on the exposed southwest side to 180 feet on the north, again decreasing to about 100 feet at the northeastern boundary formed by the eroded channel. Other platforms occur to the north which may once have been part of the Slaughter Bluff platform, but which are now separated by channels.

Compared to the previous platforms studied, the surface of the Slaughter Bluff platform is irregular, although some smooth areas do exist. In general, the more exposed areas have surfaces which are angular and contain reliefs of about 6 inches between the tops and bottoms of breccia protrusions. The sheltered area to the northeast also exhibits this characteristic, but contains flat-floored pans with diameters of up to ten feet which have bevelled across the rough surface.

Even though the surface is rough, levels can be ascertained. The sheltered northeastern portion of the platform, at about 2.0 feet msl, is close to high tide, while the surface rises in four steps of approximately 2 feet each to the west. If the previously

Photograph 13

Cape Grim Platforms. The platform in the center of the photo is the Slaughter Bluff feature.

Photograph 14

Level Pan on the Slaughter Bluff Platform.

given estimate of tidal range in the area, 3.0 feet, is correct, the horizontal surface occurs near 0.5 feet above mean higher high water. Unfortunately, these figures could be in error as no tide gauge was installed and the values are included here as an approximate indication of the conditions present. The error may be as much as $\pm$ 1.0 feet between the figures derived by inspection and those possible by tide gauge measurement.

The highest surface, approximately 8 feet above the level of the sheltered area, or 10 feet msl, is on the southwest side of the point and exhibits a slight seaward slope. No notch is present at the base of the cliff in this area and the 70° slope grades into the platform surface in a curve with a radius of about six feet. Some slight notching is present in the junction of cliff and platform in the sheltered section, but more often the intersection is in the form of a curve with a radius of about 2 feet. A small sand beach covers a portion of the sheltered platform and may mask a notch in that location.

The leading edge of the platform is not very angular, even in the more sheltered zone. Here, the platform surface meets the vertical channel wall in a curve of about 3 foot radius, while the more exposed surface has a radius similar to the junction of platform and terrestrial cliff, about 6 feet, before meeting the almost vertical submarine wall.

Weathering and Hydraulic Activity.

Like many other platforms, the Slaughter Bluff feature shows the results of both weathering and hydraulic processes. Weathering probably initially weakened the rock to allow quarrying and is now continuing in the more sheltered area to produce a horizontal, smooth surface. Wave splash on the more exposed southwest location could raise the level of saturation and thus elevate the zone of weakness in which quarrying is most effective. Although weathering allows the quarrying to act rapidly in this elevated zone, it is not in itself as active in bevelling the surface as in the more sheltered areas to the northeast, as indicated by the rough, broken surface created by waves acting upon the breccia. The stepped nature of the platform surface may be due to the dipping bedding planes in the breccia, with the material removed by quarrying when the distance between the surface and the bedding plane became small.

Weathering is more noticeable on the northeastern surfaces, but even here is not predominant. Interspersed among zones of rough breccia are areas which are remarkably flat, up to about 10 feet in diameter, having bevelled across both the bedding plane and protruding breccia (Photo 14). Joints, not visible in the breccia, are apparent on the horizontal surfaces. No sign exists of tool stones capable of carving the pans, although some sand grains are present. If abrasion were the cause of the pans, however, the exposed parts of the platform should contain them too, and no pans are found on the southwest side. There are several quite large potholes, complete with tool stones in the bottoms, but they are definitely distinct in form from the horizontal pans.

It seems most likely that the pans have been formed by weathering to a saturation base level. Some of the blocks protruding from the pan surface have distinct notches, of about a half inch radius, at their bases which is indicative of weathering activity. The distribution of the pan areas may be controlled by the composition of the breccia matrix, with some zones in the rock being more easily erodible than others. Where weathering is the most active force, the easily eroded zones may become flat floored pans with bottoms at a saturation base level. Potholes found on the high wave energy side of the platform could be the result of more active abrasion scouring the weakened matrix material. The algae, mussels, barnacles and littorinids present on the pan surfaces may all contribute to biological and biochemical weathering.

Influence of Exposure to Wave Attack on Nearby Islands.

Another example of the contrast between the exposed southwestern coasts and the sheltered northeastern locations in the Cape Grim area occurs on the two offshore islands, the Doughboys. Shelter in this case is furnished by Trefoil Island, Hunter Island and numerous reefs and shallows to the north. The Doughboys are

Photograph 15

Doughboy Islands. The exposed, southwest sides of the islands have supratidal sloping platforms. Platforms on the eastern side are lower and more horizontal.

oriented in a line to the west of the Cape, the closest being about 1500 feet offshore. Roughly oval in shape, the islands are approximately 1800 feet across on the long axis and reach a height of around 200 feet. They are composed of the same brecciated basalt from which the Cape Grim platforms are carved. The southwestern platforms on both the islands are different in both elevation and profile from the platforms on the northeastern side (Photo 15). In the exposed position, the waves have cut a sloping ramp to an elevation that appears from Cape Grim to be about 10 or 15 feet above high tide level. The ramp joins the cliff in a curve of quite large radius. The northeastern platform, on the other hand, is lower, about the level of high tide, and is much more horizontal. A distinct notch marks the junction of cliff and platform surface. Structure is not responsible for the difference in platform heights and shapes, because the dipping beds are bevelled in both cases. The explanation could be similar to that already given for the Slaughter Bluff platform; that the lower limit of weathering is at a greater elevation due to wave-splash saturation on the southwest than on the sheltered northeast side. Weathering in the exposed location speeds up the quarrying, but does not in itself create the surface, while weathering itself may be producing the horizontal surface to the northeast with the aid of waves through quarrying and transportation of material.

Future Development of Platforms.

The Doughboy platforms and the features on the Cape Grim coast will react similarly through time if sea level remains constant. In exposed locations, the platform will be extended at the expense of the cliff through the combined agencies of weathering and quarrying. The platform will be sloping, with its lower edge ultimately reaching effective quarrying base level, probably about 10 feet below low tide in this area. Platforms in sheltered areas will also form from the cliffs, but the predominant process will be weathering, producing a smooth, bevelled surface in contrast to the irregularity possessed by the exposed platforms.

Chapter 6

DON HEADS PLATFORM

Most of the Tertiary Basalts of northern Tasmania support well developed peritidal shore platforms, with many exhibiting marked horizontality. One platform in particular possesses a very horizontal surface which merits detailed attention. The platform is located at the western head flanking the mouth of the Don River, two miles northwest of the town of Devonport and 120 miles north-northwest of Hobart.

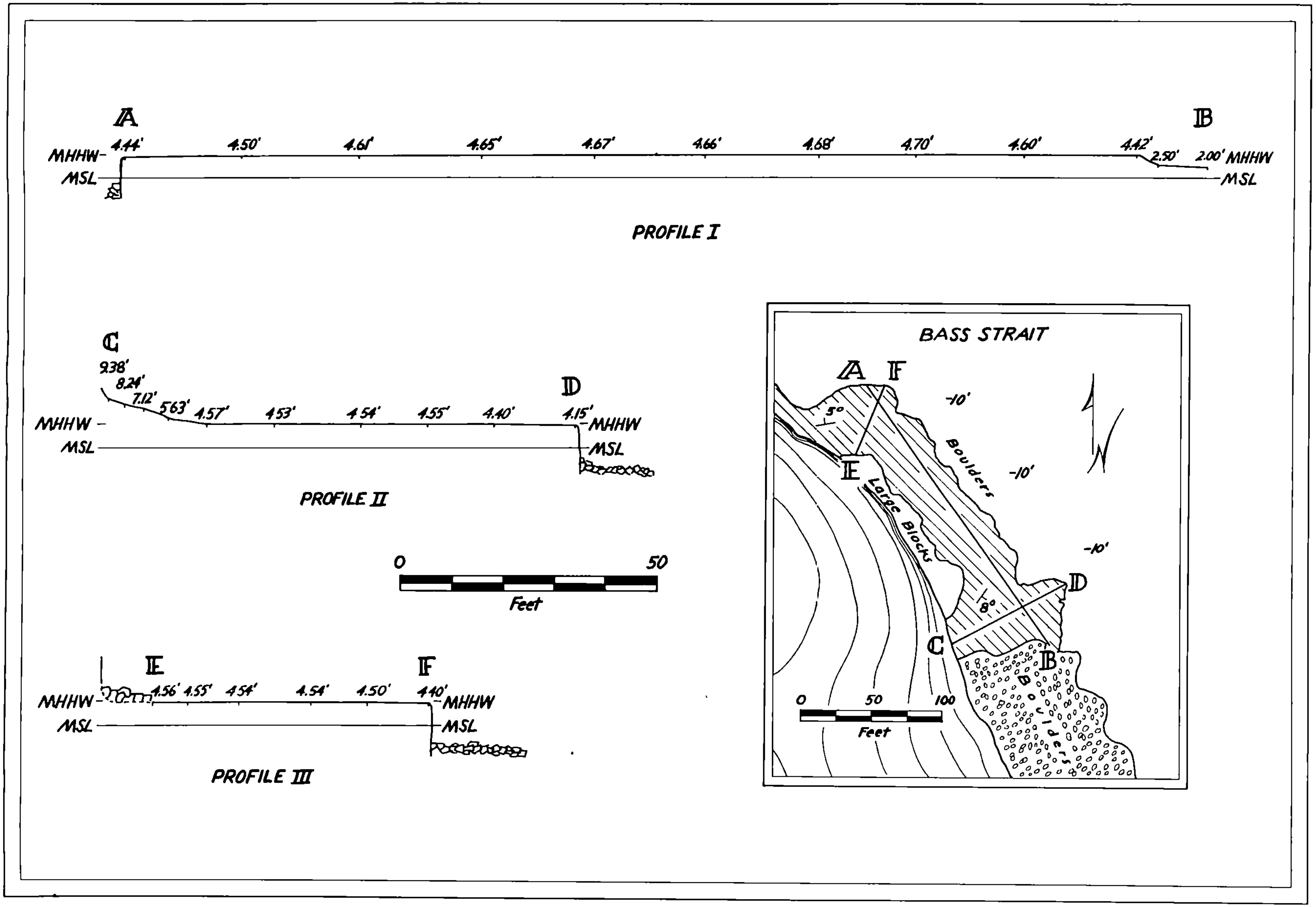
STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

Rock type is an olivine basalt which extends in flows from below sea level to the top of the cliff, 150 feet high. The basalt is well jointed in both vertical and horizontal planes with vertical, hexagonal jointing and horizontal master sheet jointing common. In the vicinity of the surveyed platform, the arched flows plunge gently seaward and have limbs dipping north at about 5^{o} and southeast at approximately 8^{o}, with the axis of the flow occurring on the northern half of the platform.

A number of platforms, separated by depressed areas filled with quartzite cobbles and basalt boulders, lie at the foot of the sea cliffs at Don Heads. The platforms are generally at the base of the steeper, sometimes vertical portions of the cliff, while the

Figure 10

DON HEADS PROFILES


A
B
MHHW
MSL
4.44'
4.50'
4.61'
4.65'
4.67'
4.66'
4.68'
4.70'
4.60'
4.42'
2.50'
2.00'
MHHW
MSL
PROFILE I
C
9.38'
8.24'
7.12'
5.63'
4.57'
4.53'
4.54'
4.55'
4.40'
D
4.15'
MHHW
MSL
MHHW
MSL
PROFILE II
0
50
Feet
E
F
MHHW
MSL
4.56'
4.55'
4.54'
4.54'
4.50'
4.40'
MHHW
MSL
PROFILE III
BASS STRAIT
A
F
E
D
C
B
5°
8°
-10'
-10'
-10'
Boulders
Large Blocks
Boulders
0
50
100
Feet

depressed areas are backed by more gentle, vegetation mantled slopes. The depressed areas apparently consisted of rock which was more easily eroded, through differences in jointing or composition, than materials comprising the flanking platforms. Bedrock is visible in the depressed areas at a level of about -3.0 feet msl where it is now being actively abraded by rock and sand.

Offshore topography typically consists of a zone of boulders at the foot of the seaward edge of the platforms, extending about 30 feet offshore. The boulder beds slope from about -4 feet to -10 feet msl over this distance. The blocks are angular and the beds have a thickness that makes sufficient movement to scour a submarine platform improbable. Further offshore, areas of sand alternate with rock as depths increase uniformly to -30 feet over a span of about 2000 feet.

CLIMATE

Climate in the Don Heads area is similar in many respects to the Cape Grim conditions, with a few variations. Winter temperatures are about the same, with the extreme lowest temperature above 25°F. and the July temperature averaging about 48°F. However, summer temperatures are higher at Don Heads where the extreme highest temperature is close to 95°F. and the January mean is about 61°F. The higher temperatures would yield a greater evaporation rate than that found at Cape Grim. Rainfall in the two areas, 30 to 40 inches, is also analogous, but the winds are different. The predominantly westerly flow at Cape Grim gives way to a more pronounced summer north-south land and sea breeze regime at Don Heads, although a strong westerly component is still present.

WAVE CHARACTERISTICS

Waves are distinctly different in the Don Heads area from those prevailing on the west coast. The southwesterly swell has been refracted almost out of existence and the coast is directly exposed only to the north. The fetch is limited in this direction by the Victorian coast, about 200 miles away. Northerly gales over this fetch could raise a sea with significant wave heights of about 8 feet. Waves of this height are rare, however, and the more common heights are about 3 or 4 feet, resulting often from summer sea breezes or more widespread northerly air flow.

TIDAL REGIME

Tides at Don Heads, with its Bass Strait location, have a much greater range than those on the other exposed coasts of Tasmania. Data recorded by the Devonport Marine Board tide gauge shows a maximum range of 13.1 feet for this coast. Mean higher high water is 9.9 feet, mean sea level is 5.3 feet, and mean lower low water is 0.8 feet, yielding a mean range of 9.1 feet. Tides are on the borderline between semidiurnal and mixed, predominantly semidiurnal, as $\frac{K_1 + O_1}{M_2 + S_2} = 0.214.$

THE PLATFORM

The platform selected for study at Don Heads is approximately rectangular in shape and measures 199 feet in the northwest-southeast direction and about 50 feet in the southwest-northeast dimension. Boundaries are established on the northwest by an eroded channel, on the northeast by a vertical drop of about 8 feet to a boulder bed, on the southeast by a sloping surface covered with boulders, and to the southwest by a vertical cliff 50 feet high. Large blocks of basalt lie in storage on the rear of the platform at the foot of the vertical rock face. Wave action may have moved them to the rear of the platform, but the blocks do not have the appearance of having been displaced recently or repeatedly.

Extreme horizontality.

Most impressive feature of this particular platform is the extreme horizontality exhibited on its surface (Photo 16). Three profiles, obtained by theodolite levelling with a datum determined through the use of a portable tide gauge, clearly showed the marked horizontality which exists over the approximately 10,000 square foot area of the exposed platform. Profile I, taken on an azimuth of 311°, varies only 0.28 feet over the entire 199 foot distance (4.42 to 4.70 feet msl). The variation is even less over the 85 foot center portion of the profile; from 4.70 to 4.65 feet msl, or 0.05 feet.

Taking the mean range for Don Heads tides as 9.1 feet (the nearby Devonport figure), the platform surface lies between 0.13 feet below and 0.15 feet above mean higher high water. Most of the platform occurs near the higher elevation, about 0.10 feet above the mean higher high water level.

Profile II cuts across the width of the platform at an azimuth of 40°, intersecting the first profile. This measured surface is also quite flat, with heights differing from 4.40 feet to 4.15 feet over a 72 foot profile and from 4.57 to 4.54 feet over a 43 foot segment. Horizontality abruptly ceases about 20 feet seaward from the cliff as the rock surface changes elevation from 4.57 to 9.38 feet msl in this area.

A third profile was measured on the northwestern end of the platform which again intersects the long Profile I. Profile III, taken on an azimuth of 189°, extends from the rocks flanking the base of the cliff to the platform edge 53 feet away. Total variation over this span is 0.16 feet, from 4.56 to 4.40 feet msl. The lowest elevations are again nearest the edge of the platform, in common with levels noted on the previous two profiles.

Developmental Factors.

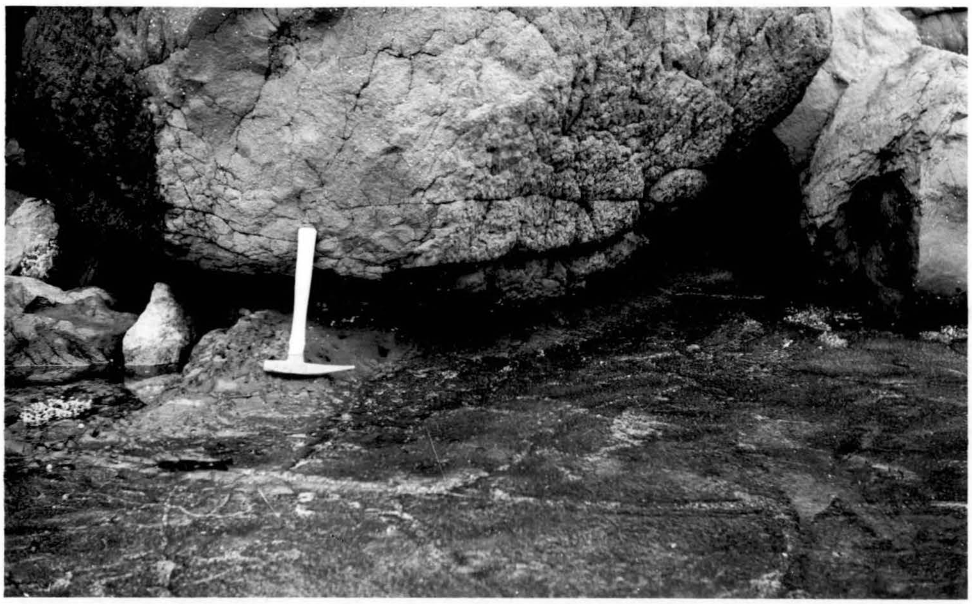
Although the rock type is quite different, the forces which produce horizontality are probably similar to those bevelling the beds at Eaglehawk Neck. Chief among the processes are wave quarrying and subsequent weathering to a base level furnished by saturation.

Photograph 16

Don Heads Platform.

Photograph 17

Blocks on Platform. The blocks are resting on a surface which is higher than the general platform level.



In the Don Heads area pronounced vertical jointing combined with numerous horizontal master sheet joints would facilitate initial quarrying to a level where weathering could produce the very horizontal surfaces present.

The surveyed platform probably formed fairly recently, after a rapid rise in sea level. Wave action first removed the weathered zone on the newly inundated slope and then began quarrying bedrock from the face. At the same time, weathering was weakening the rock in the sub-aerial zone. Weathering and quarrying working together produced a convexity of slope which may have centered on the horizontal master sheet joint which presently can be traced in the sea cliff where it attains a height of about 10 feet above the present platform surface. Water-layer weathering may have become the relatively most important process when random weathering and quarrying had produced an incipient bench. Weathering is now probably the most effective process working on the platform, with wave action usually having a relatively minor role, mostly in the removal of material. Quarrying apparently requires the help of weathering to be effective in this area, as the leading edge of the platform, at saturation base level, shows little of the stepped form usually associated with quarried platform edges. Some quarrying may still be occurring at the rear of the platform, but the presence of a notch about six inches high and one inch deep at the junction of the cliff and the platform suggests that weathering is the most active force (Photo 18).

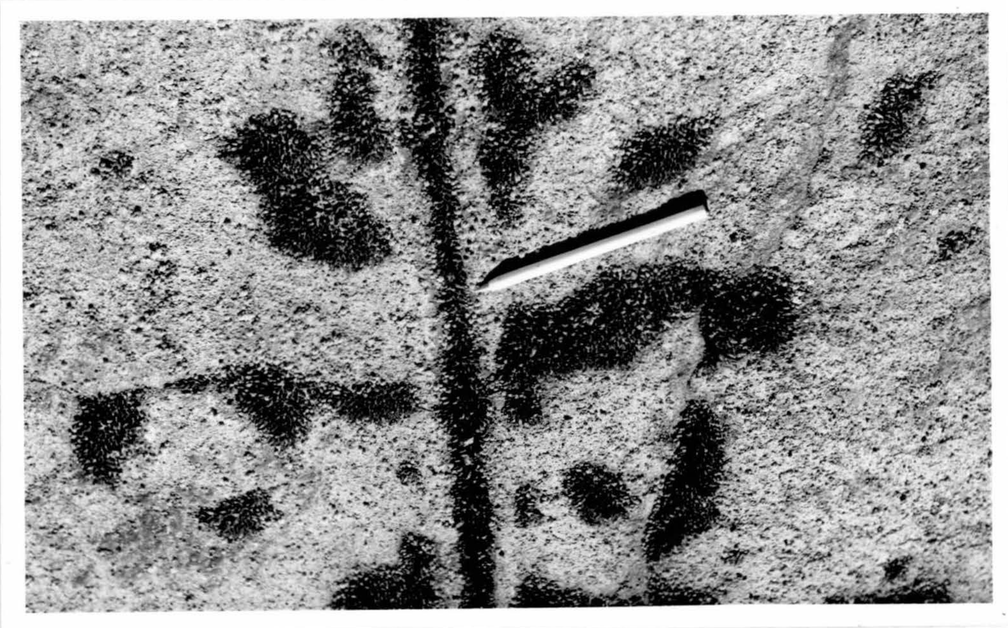
The mass of very large boulders on the platform surface near the cliff also may indicate a fairly rapid removal of material at a level just above high tide, undercutting large blocks of the slightly more resistant flow above. The blocks could not have come from the slope above the vertical cliff because that slope is smoothly mantled with soil and vegetation. They might have been tossed to the rear of the platform by huge waves which stripped them from the leading edge during a storm, but it is more probable that they fell from the cliffs above. The blocks are perched on a level about 6 inches above the elevation of the horizontal part of the platform. The elevated portion corresponds exactly to the outline of the boulder area, and even to the individual boulders themselves. The best explanation is that the boulders fell on the platform surface when it was at a higher level and that the level has been preserved by the boulder cover. If abrasion were active in lowering the platform surface, tool stones might be expected to be present jammed in and around the boulders, but they are absent. If weathering were the operative agent, the boulders may have protected the surface by inhibiting drying and thus reducing or eliminating wetting and drying cycles. Whatever agency is lowering the platform surface is working quite rapidly, because relatively little weathering has taken place on the boulders during the time that the unprotected surface seaward has dropped about 5 inches. An area to the

Photograph 18

Junction of cliff and Don Heads Platform. A small notch occurs at the base of the cliff.

Photograph 19

Joint on Don Heads Platform. Ridges flank the joints, which have been colonized by the mussels, *Modiolus pulex*. Small white molluscs are *Melarapha unifasciata*.



northwest of the boulders has also been lowered by the same amount.

Hydraulic stripping to a master sheet joint is also suggested by the southeastern, sloping portions of the platform. Profile I shows a drop from the platform surface at 4.42 feet msl to a level of 2.00 feet msl 14 feet to the southeast. The transition from the horizontal platform surface is not abrupt; the surface grades evenly onto the slope. The slope may represent the top of a dipping master joint which has been stripped by wave action and is not bevelled, because of its position below saturation level.

Profile II depicts a slope rising from the platform surface for a vertical distance of 4.81 feet over 20 feet. In contrast to the descending slope mentioned previously, the rising surface has a sharp break at its base where it joins the horizontal platform. The morphology suggests a bevelling of the sloping surface to a base level. This same sloping surface may be continuous with the raised area which has been protected by the boulders to the northwest. Jointing is prominent on both the sloping and horizontal surfaces, but its expression differs in the two locations. Joints on the upper slopes are depressed about 2 inches below the surface of the included block, while joints on the horizontal surfaces are depressed 1/4 inch and are flanked by ridges about 3/16 inch high (Photo 19). This situation is also similar to joint characteristics found at Eaglehawk Neck.

Organisms.

Most obvious organisms on the platform are the molluscs, with mussels and periwinkles quite common. The mussels, Modiolus pulex, live on the horizontal surface of the platform, often inhabiting the joints where moisture remains when the rest of the platform surface dries at low tide. Periwinkles, represented by Melarapha unifasciata and the tiny Melarapha infans occur mainly on the horizontal surface, but also range up the slope in decreasing numbers. The flat areas also support scattered colonies of barnacles, Chamaesipho columna. Algae are not obvious on the platform. Minute green algae upon which the periwinkles feed occur on the horizontal surfaces and flanking slopes, but the leading edge of the platform is free of the coating of Durvillea often found elsewhere in Tasmania. Pollution may have caused its disappearance (the Devonport sewer outfall is just offshore) or the higher temperature of the water in Bass Strait may have prohibited its growth. Even though the plant and animal life is not luxurious on the Don Heads platforms, it is still probably adequate for some biochemical and biological erosion.

Future Development of Platform.

The future for the Don Heads platform if sea level remains constant will be a slow advance of the platform at the expense of the vertical cliff combined with loss of horizontality on the platform edges. The leading edge itself may be quarried occasionally, but its vertical configuration will probably remain. The advance of the horizontal platform would decrease gradually as the effective height of the sea cliff increased due to erosion at its base. Eventually, the configuration at the junction of the cliff and the platform would resemble the notched intersection now present only on the northwest corner, unless boulders continued to mask the surface. The profiles show a slight slope from the center of the platform to the seaward and lateral edges, amounting to only about a tenth of a foot over a distance of 20 or 30 feet. This slope may be due to occasional rock abrasion or erosion by moving water. This activity, coupled with biological action, might in time reduce the horizontality of the present platform.

Chapter 7

WEYMOUTH PLATFORM

A number of basalt platforms in northern Tasmania have surfaces which bear little resemblance to the planar Don Heads feature. Remnant knobs protrude above a horizontal surface flanking the joints on these platforms, producing a morphology similar to the Waffle Iron at Eaglehawk Neck. Summits of the columns are irregular, but the flat areas at their bases occur at an elevation near mean higher high water over a considerable area.

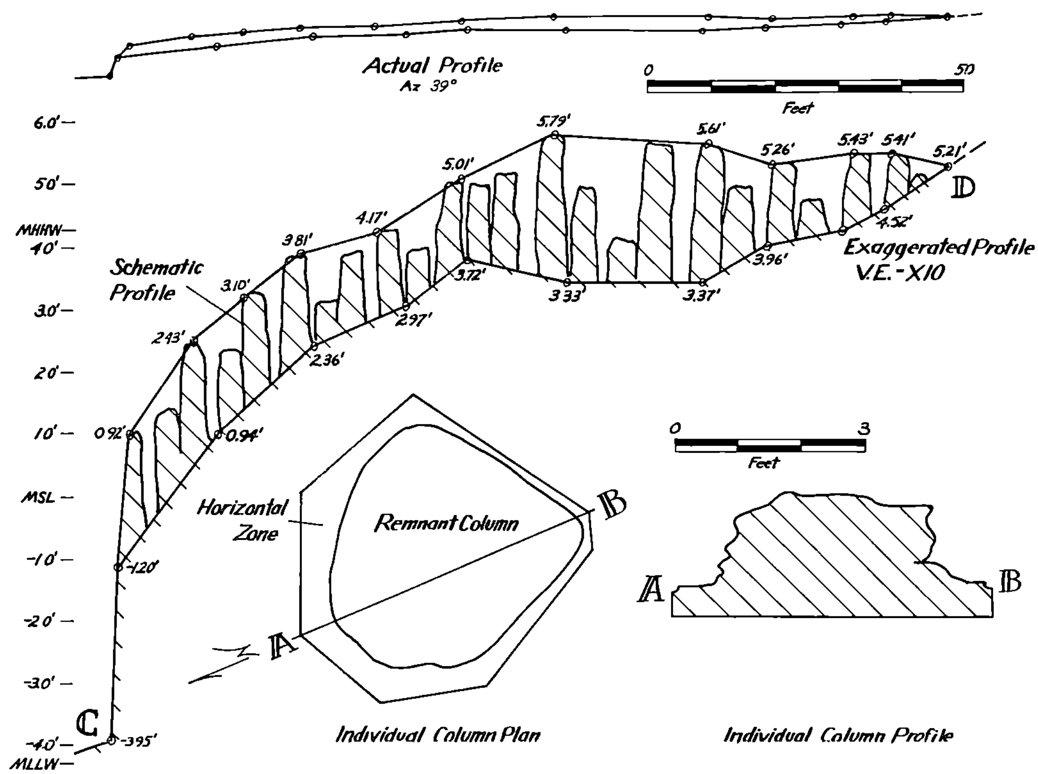
Rough-surfaced basalt platforms are located near Devonport, further east at the West Head of the Tamar River, and still further east at Weymouth. The Weymouth basalt platform is the most extensive of these features and was studied in detail. Weymouth is a small resort town on the coast 45 miles east of Devonport and 125 miles directly north of Hobart. The town is sited immediately to the west of the mouth of Pipers River which flows into Noland Bay.

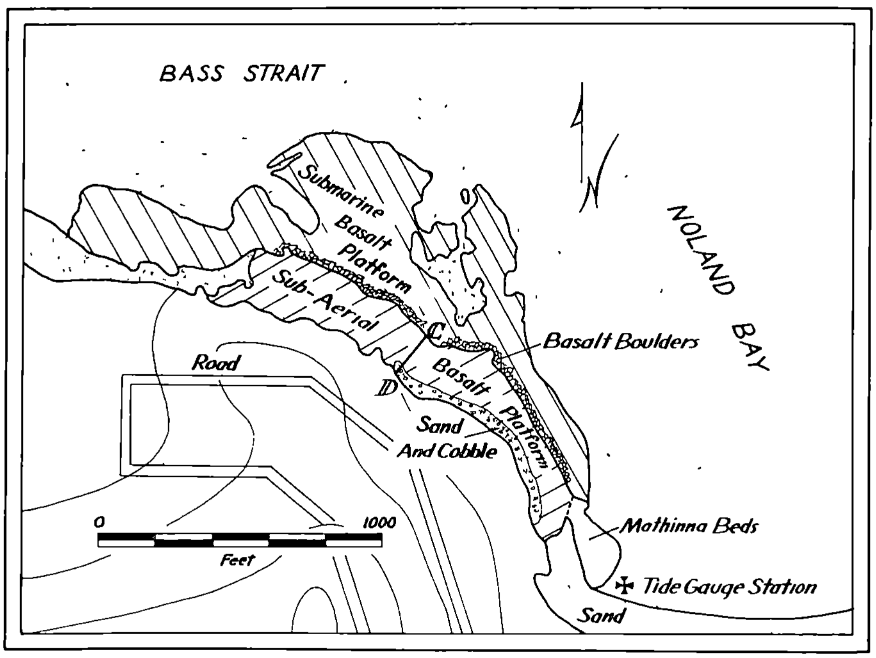
STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

Two major rock types occur at Weymouth; the most prevalent rocks are Siluro-Devonian sediments, which have been overlain by flows of Tertiary Basalts. The basement rocks carry the name of Mathinna Beds and consist of steeply dipping sandstones in this area. Basalts at Weymouth have covered much of the Mathinna Bed

Figure 11

WEYMOUTH PROFILE AND REMNANT COLUMN DETAIL


Actual Profile
Az 39°
0
50
Feet
6.0'
5.0'
MHHW
4.0'
3.0'
2.0'
1.0'
MSL
-1.0'
-2.0'
-3.0'
-4.0'
MLLW
Schematic Profile
Exaggerated Profile
V.E.-X10
5.79'
5.61'
5.26'
5.43'
5.41'
5.21'
5.01'
4.17'
3.81'
3.10'
2.43'
0.92'
0.94'
2.36'
2.97'
3.72'
3.33'
3.37'
3.96'
4.52'
-1.20'
-3.95'
C
D
Horizontal Zone
Remnant Column
A
B
0
3
Feet
Individual Column Plan
Individual Column Profile


BASS STRAIT
NOLAND BAY
Submarine Basalt Platform
Sub-Aerial
Basalt Platform
Basalt Boulders
C
D
Road
Sand And Cobble
Mathinna Beds
Tide Gauge Station
Sand
0
1000
Feet

basement on the western margin of the town to depths of at least 20 feet at the shoreline. The basalts show well developed polygonal vertical jointing and also exhibit pronounced horizontal structure.

Sub-aerial topography to the northwest of Weymouth consists of a sloping surface, covered with soil and vegetation, which is interrupted by a small sea cliff having a basalt shore platform at its foot. The sloping surface is overlain to the southwest by a vegetation stabilized sand dune from under which it emerges at a height of about 20 feet msl. The surface drops over about 300 feet to approximately 12 feet msl at the top of the eroded vertical cliff. At this point, near 6.0 feet msl, the basalt platform extends seaward to the northeast.

Off the edge of the sub-aerial platform lies a jumbled mass of basalt boulders at a depth of -4.0 feet msl. A bedrock surface becomes apparent as the boulder veneer thins out about 20 feet from the edge of the exposed platform. The bedrock surface occurs at a depth of about -6 feet and consists of a series of remnant columns, with tops within two feet of the same depth. Depressed joints packed with cobble and boulders typically surround the columns. *Durvillea* is again absent, but the rocks are profusely covered with other smaller, algal species. Depths gradually increase to the northeast as patches of sand become interspersed with the bedrock exposures. About 500 feet from the edge of the sub-aerial platform the rock becomes entirely covered by sand at a depth of approximately -15 feet msl. The offshore slope continues at a low gradient, reaching -25 feet msl about 1200 feet offshore where bedrock is again exposed.

CLIMATE

The Weymouth climate is much the same as Don Heads, except for slightly less precipitation, between 20 and 30 inches annually, in the more easterly location. Temperatures average about 62^{o} in January and 48^{o} in July, with an extreme highest reading of about $90^{o}F$. Extreme lowest temperature was above $25^{o}F$. Evaporation is probably about 35 inches per year, although no records are kept in the area. As at Don Heads, a strong land-sea breeze regime is normally established in the summer, with winds blowing mainly north and south. Again, a westerly component can be present any time of year, but maximum expression is usually in the winter months.

WAVE CHARACTERISTICS

Wave conditions are essentially the same as elsewhere on the northern Tasmanian coast with fetch limited by the Australian mainland some 200 miles to the north. Waves with significant heights of 8 feet might occur during northerly gale conditions, but the coast is struck more commonly by waves of about three or four feet in height created by summer sea breezes and other moderate northerly flows of air.

TIDAL REGIME

Although long-term tidal data is unobtainable for Weymouth itself, measurements have been made at points both east and west of the town. Tidal characteristics are available for Georgetown on the Tamar River, 20 miles to the west and on Waterhouse Island, 30 miles to the east. Georgetown mean heights in feet are: high water springs, 10.6; high water neaps, 10.0; low water springs, 2.4; low water neaps, 3.1. These figures yield a mean range of 8.2 feet for spring tides and 6.9 feet for neaps. Waterhouse Island values for mean heights are lower, as might be expected in view of the location nearer Banks Strait and the open water of the Tasman Sea. Mean heights here are listed as high water springs, 8.0; high water neaps, 7.0; low water springs, 1.0; and low water neaps, 2.0 with all heights again in feet. Mean ranges are lower than those at Georgetown, with Waterhouse Island having a range of 7.0 feet for springs and 5.0 feet for neap tides.

Weymouth tides probably have characteristics somewhere between those found at Georgetown and Waterhouse Island, with Georgetown being the most representative. Assuming this to be the case, Weymouth could have a spring tide range of about 7.9 feet and a neap tide range of 6.5 feet. A conversion to the mean higher high water datum used on previous platforms can be made with sufficient accuracy by utilizing differences between mean high water springs and mean higher high water at Devonport, and scaling linearly.

The conversion gives a value of 4.3 feet msl as the level of mean higher high water at Weymouth. No harmonic constants are listed for Waterhouse, but Georgetown figures yield $\frac{K_1 + O_1}{M_2 + S_2} = 0.231$, which indicates a semidiurnal form which is on the borderline of mixed, predominantly semidiurnal. Thus there are daily occurrences of two high and two low waters having some inequalities in height and phase.

THE PLATFORM

The Weymouth basalt platform is arcuate in form, and extends 1500 feet along the coast in a northwest-southeast direction. The platform is apparently carved in basalt which occupies a former Tertiary valley. Northwestern and southeastern boundaries are probably the edges of the original flow where slopes limited lateral spreading. Width of the platform averages 200 feet over most of the 1500 foot length. Landward boundary is a sea cliff dropping from 12 to 6 feet msl which is vertically cut through a soil profile for about the top four feet and is mantled at its base by sand and cobble about two feet deep. Although the base of the cliff is hidden, it is probable that the basalt extends beneath the rising surface to the southwest. The seaward edge of the platform is delineated by a drop of about five feet to another concordant surface at -6.0 feet msl. The lower surface may be the top of another flow, a horizontal sheet joint plane or a result of weathering during a period of lower sea level.

Remnant Columns.

The most interesting feature of the platform, and the reason for inclusion in this survey, is the marked duality of levels (Photo 20). One level, between about 5 and 6 feet msl, is described by the tops of remnant basalt columns and the other represents the elevation of the horizontal zones surrounding the joints, approximately 3.5 feet msl.

In order to more accurately describe the Weymouth platform, a profile was obtained using the theodolite at an azimuth of 39° True. Sea level datum was determined with the portable tide gauge because Weymouth is not tied precisely to any survey. Measurements on the platform were taken from the cobble at the base of the cliff to the seaward edge of the basalt, a total distance of 135 feet. The profile is drawn at both true and exaggerated vertical scales, with the 10 to 1 exaggeration plotted to emphasize the structure. Two lines appear on the profile; the upper line connects points measured on the tops of remnant columns and the lower line links measured joint elevations.

In general terms, both the column tops and the joints rise in a steady convex upward curve for 55 feet landward of the leading edge of the platform. At this point the column tops continue to gain elevation for another 30 feet, while the joint elevations level

Photograph 20

Remnant Basalt Columns at Weymouth. The tide has just flooded the flats surrounding the columns. Molluscs are *Melarapha unifasciata*.

Photograph 21

Remnant Basalt Columns at Don Heads. Rock abrasion is modifying a surface now at the level of mean lower low water which may have previously resembled the Weymouth Platform.

out and even drop slightly for the next 40 feet. The columns ultimately reach a height of about 5.5 feet msl and continue to the base of the sea cliff at this elevation. Joint elevations rise rapidly 40 feet from the southwestern end of the profile, nearing the level of the column tops just at the point where the cobble buries the entire platform. Joints and their flanking flats are located between 3.72 feet and 3.33 feet msl for a horizontal distance of 44 feet and are level at 3.33 feet for a distance of 22 feet. As stated earlier, mean higher high water is 4.3 feet msl. The surface at 3.33 feet msl therefore lies 0.97 feet below mean higher high water level, while the 3.72 foot elevations are 0.58 feet below that datum.

More detailed study was made of an individual column in the zone showing most horizontality of joint surroundings. The column was outlined by a seven-sided polygonal joint structure averaging 4.7 feet in diameter. Immediately adjacent to the joint was a notch about one inch wide and one inch below the level of the flat surrounding the column center. The flat varies in width on different sides of the column, being widest, 8 inches, on the northeast and narrowest, one inch, on the southeast. The northern side in general has the widest flats which may be due to increased evaporation through exposure to direct sunlight, resulting in more wet-dry cycles than occur on the shady sides of the columns. The rising portion of the column, towards the center from the flat areas, may show either a notch of about 1/4 inch radius or a ramp sloping upward for approximately an inch.

A profile of the column shows an expression of the horizontal jointing which has been emphasized by erosion. A series of indentations about 5 inches apart occur on the norhtern side of the column, while re-entrants are fewer on the south side. The top of the column slopes irregularly towards the south, the surface dropping 2 inches over a span of 24 inches.

Examination of other columns shows a progressive change in morphology and biotic representatives across the platform from seaward edge to sea cliff. Nearest the sea, the columns slope directly up from the joints, with no intervening flats. Tops of the columns are pitted, but the sides are often smooth and rounded in appearance. Most obvious inhabitants of this zone are the small periwinkles, *Melarapha unifasciata*; mussels, *Modiolus pulex*; and white barnacles, *Chamaesipho columna*. About 40 feet inland from the seaward edge of the platform, the columns still rise directly from the joints, but show a concavity of slope in the zone nearest the joint planes. The entire surface of the column is pitted, in contrast to the smooth portions on the seaward columns. This location appears to be hospitable only to the hardy *Melarapha* and the microscopic algae upon which it feeds. Columns become increasingly lower and smaller in diameter as the seacliff is approached. In a few locations, the columns have been entirely reduced leaving a horizontal surface cut by polygonal joint patterns.

Developmental Factors.

The Weymouth basalt platform owes its present morphology to a number of complex factors. One is the original presence of a flat surface represented by the summits of the remnant columns. This surface could have been either the top of a flow, a basal plane of weathering dating to the time before the surface was exposed by wave stripping, or an ancient shore platform. Hydraulic action is another factor, acting through erosion and transportation. As sea level reached its present height, wave action may have removed the completely weathered material and soil from the surface, exhuming a mass of basalt which was probably at least partially weathered, especially in the joints.

The sea acting on the newly exposed surface may have removed material from around the columns by quarrying, rock abrasion, and in the case of extremely weathered rock, unarmed water abrasion. As the overburden was removed landward, the effectivity of wave action was probably reduced by the energy dissipating surface of lowered joints and remnant columns. Sub-aerial weathering may have become the most effective force, with wave action serving mainly to remove weathered material.

Weathering has apparently reduced a portion of the columns to a base level at 3.5 feet msl, between about 55 and 95 feet from the seaward edge. This level is slightly lower in relation to mean higher high water than the Don Heads platform, possibly due to reduction of wave splash by the interfering seaward columns. Another interesting characteristic of the base level weathering is the rise in elevation landward of the extensive horizontal zone. The flats flanking the joints have the same morphology as those in the 3.5 feet msl zone, but occur at gradually greater elevations towards the southwest, reaching a height of 4.5 feet just before being buried by cobble. A possible explanation may be that the base level at the rear of the platform is established by ground water saturation while the 3.5 feet msl level is related to the marine environment.

It is difficult to explain the occurrence of the joint-flanking flats by any other process than weathering. Wave quarrying of material surrounding the remnant columns may take place on the seaward edge of the platform, but wave energy 85 feet inland from that edge would be insufficient to quarry to a horizontal flow or joint plane. In addition, wave action would probably not be strong enough to cause efficient rock abrasion. Tool stones, in the form of rounded basalt and sandstone cobble, are present at the rear of the platform, but few are found lodged in joints seaward. A rock abrasion formational theory would also be hard-pressed to explain the horizontality of the flats. An area at Don Heads, located below low tide level seaward of a cobble beach, shows the type of surface which rock abrasion produces in columnar basalt (Photo 21). The basalt surface may have looked like the present Weymouth platform when sea level was lower, complete with flats and remnant columns. Now, however, rock abrasion has degraded all the surfaces, leaving only a suggestion of horizontality.

Future Development of Platform.

The future of the Weymouth platform, if sea level remains constant, will be first a complete bevelling of the surface to 3.5 feet msl or slightly higher to the southwest. Areas now below the 3.5 feet msl level of saturation would continue to erode randomly under the attack of quarrying, abrasion and biota. Given enough time, the bevelled area, too, would probably succumb to these forces and be reduced to a sloping surface. As the leading edge was being reduced, new platform would be continuously produced through removal of overburden to the southwest.

PART TWO

PLATFORMS WITH SLOPING SURFACES

Chapter 8

TASMAN ISLAND PLATFORMS

The platforms discussed previously have all had a horizontal surface near the level of mean higher high water. Another type of Tasmanian shore platform has a surface sloping towards the sea. Many of these platforms occur on the igneous coastlines, in the eastern half of the state. Slopes vary from about 3° to over 45° on the platforms which frequently have a uniform surface.

Some good examples of sloping platforms are located on the doleritic[1] coastline of the Tasman Peninsula in southeastern Tasmania. This very spectacular coast has some 40 miles of dolerite exposure, much in the form of cliffs several hundred feet high. Tasman Peninsula is joined to the mainland by Eaglehawk Neck and is about 30 miles directly southeast of Hobart.

STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

The dolerite was intruded into Permian and Triassic sediments about 165 million years ago in the Middle Jurassic Epoch. The form of the intrusions varies from concordant or slightly discordant

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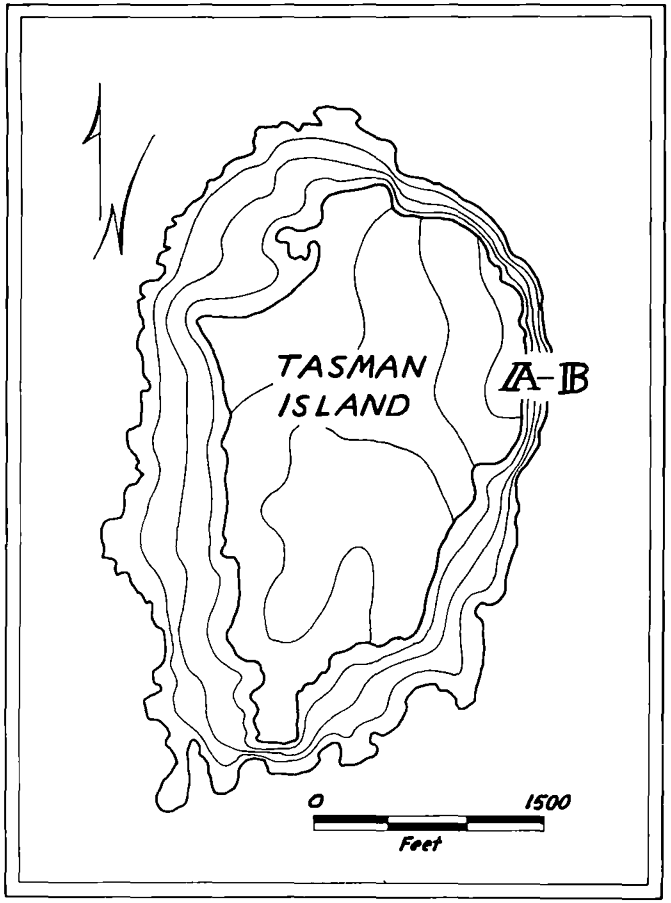
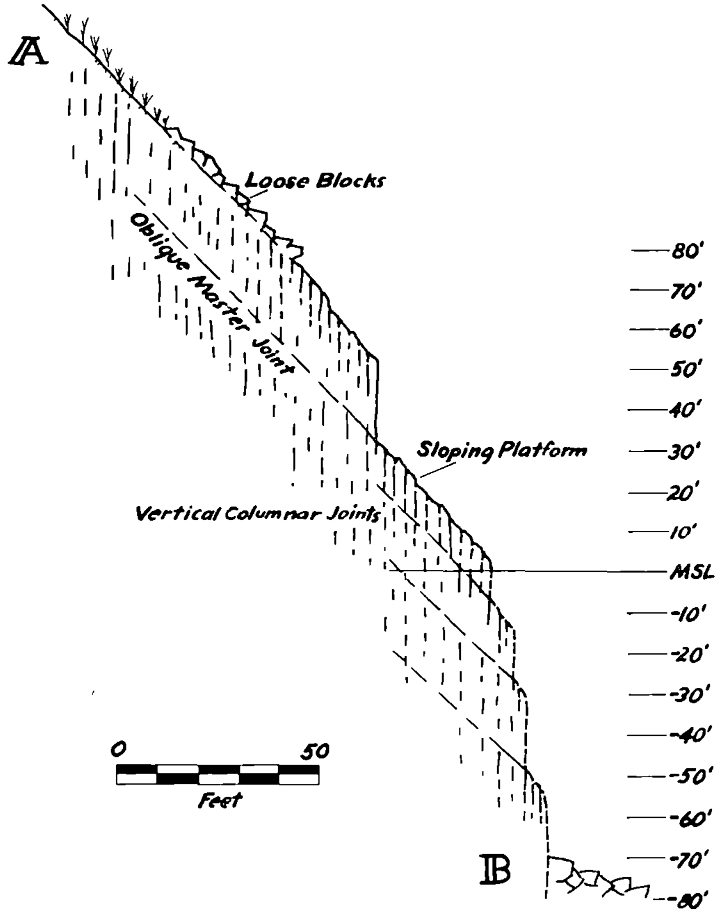
[1] Throughout this thesis, the Tasmanian convention for the differentiation between dolerite and basalt is followed. The geologic literature in Tasmania generally labels the intrusive igneous rocks of Jurassic age dolerite and the predominantly extrusive Tertiary rocks basalt. This chronologically based division is usually adequate and greatly facilitates the discrimination between two closely allied rock types.

Figure 12

TASMAN ISLAND SKETCH PROFILE



TASMAN
ISLAND
A-B
0
1500
Feet



A
Loose Blocks
Oblique Master Joint
Sloping Platform
Vertical Columnar Joints
80'
70'
60'
50'
40'
30'
20'
10'
MSL
-10'
-20'
-30'
-40'
-50'
-60'
-70'
-80'
0
50
Feet
B

sills to vertical dikes, with the sills ranging in thickness from a few feet to about 1500 feet. An impressive feature of the dolerite is the pronounced columnar jointing which Carey (1961) suggests may be the result of cooling stresses or epeirogenic uplift. Non-vertical jointing also occurs, but it does not have the frequency or polygonal structure of the vertical patterns. Extensive oblique master sheet joints are found and Hale (1961) describes radiating or curved cooling joints roughly parallel to the unloaded surface.

Tasman Island, separated from the southeastern tip of Tasman Peninsula by a 400-yard passage, has a coastal morphology which typifies the area. Dolerite forms the bulk of the island - the only other rock present is a small outcrop of Permian sediments on the northwest end. The gently sloping top of Tasman Island is about 850 feet above the sea and is generally bounded by vertical, 300 foot cliffs of columnar dolerite. At the foot of the cliffs lies a uniform 45^{o} slope which continues without interruption to within about 50 feet of mean higher high water. The slope is generally mantled with a thin soil cover and sparse vegetation and is strewn with blocks which have fallen from above. High seas have swept the vegetation and soil from the 45^{o} slope to heights of at least 100 feet in places. Not all of the island is flanked by 45^{o} slopes, however. Vertical cliffs plunge from about 500 feet directly into the sea on the southwestern tip and the northern side of the island has plunging cliffs of lesser magnitude.

CLIMATE

The climate of Tasman Island is influenced by its maritime location at the extreme tip of Tasman Peninsula. The month of January, 1965, had an average maximum temperature of 57.4°F. and an average minimum of 49.5°. Average maximum and minimum temperatures for July were 49.6°F. and 41.6°F. Precipitation at Tasman Island averages about 38 inches per year, approximately the same as Eaglehawk Neck to the north. Winds vary from afternoon sea breezes during the summer to southeasterly and southwesterly gales which are most common in the winter months.

WAVE CHARACTERISTICS

Tasman Island is struck frequently by high energy waves. Most prevalent wave type is the southwesterly swell which averages about 8 feet in height. During southerly gales, storm waves combine with swell to reach large dimensions - fishermen tell of unbroken waves over 30 feet high. It is possible that once every 100 years the wave height may reach 50 feet. Records kept by lighthouse staff showed that the seas were 13 to 20 feet high on 20 separate days during 1965-1966. Because of its exposure to both southeasterly and southwesterly seas, Tasman Island probably is struck by more high energy waves than almost any other location on the Tasmanian coast.

TIDAL REGIME

No tide data is available for Tasman Island, but conditions should differ little from those at Eaglehawk Neck. Eaglehawk Neck tides were mixed, predominantly semidiurnal with a range of 2.6 feet between mean higher high water and mean lower low water.

THE PLATFORMS

The zone between mean higher high water, at about 1.3 feet msl, and the bottom of the 45° slope often consists of a slanting bedrock surface backed by a cliff of columnar dolerite (Photo 22). Horizontal platforms like those found in the northern Tasmanian basalts do not occur, even on the sheltered side of the island. The sloping dolerite platforms sometimes have a fairly uniform surface, but often exhibit a less regular, stepped profile.

From the approximate high tide level, the slope drops nearly vertically to a depth of about 80 feet, where an extensive horizontal surface is abruptly encountered. On a rare calm day, it is possible for vessels of considerable draft to come within an oar's length of the _Durvillea_ covered rocks.

The scarcity of horizontal platforms on Tasman Island (or almost any other doleritic coast) is puzzling. Extreme wave action might inhibit formation of a platform on the struck side of the island, as on the Doughboys near Cape Grim, but a platform on the sheltered side could be expected. Although a horizontal platform does exist on the sheltered side of Tasman Island, it occurs only in the Permian sediments, while flanking dolerite surfaces either plunge vertically or are sloping. If dolerite were very resistant to sub-aerial weathering, it might be precluded from being host to horizontal platforms. However, dolerite, with much the same chemical composition as basalt, can weather quite rapidly and often shows pitting in the peritidal environment.

Chief reason for the lack of horizontality may be the structure of the dolerite sills themselves. All of the platforms previously described as showing good horizontality occurred in rocks which were well bedded and jointed, with small distances between planes of weakness. The dolerite has well developed vertical jointing, but horizontal jointing is irregular and widely spaced. In addition, quite pronounced widely spaced master joints cut the dolerite obliquely, some at about 45° as in the case of Tasman Island. It is possible that weathering alone is not capable of producing a platform from a sloping surface.

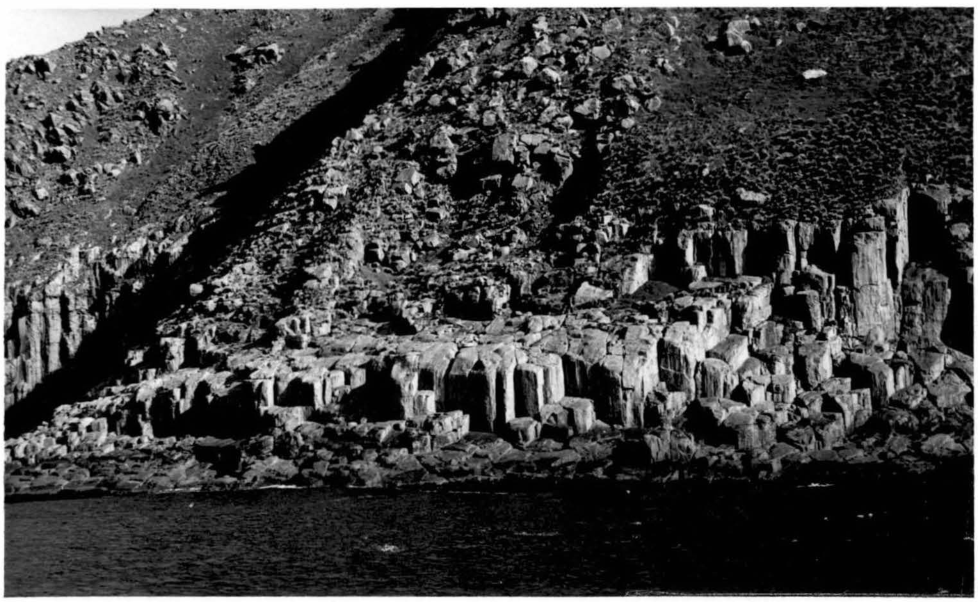
Wave stripping offers one mechanism by which some degree of horizontality could be established in favorable rocks, near the level of mean higher high water. Waves are presently stripping weathering-loosened material from this level as indicated by the sloping platform. However, the widely spaced oblique jointing does not favor the establishment of even crude horizontality, presenting weathering with the difficult task of removing a huge

Photograph 22

Eastern side of Tasman Island.

Photograph 23

Sloping Shore Platforms on Tasman Island.



mass of rock in producing a horizontal platform.

Formation of Platforms.

The formation of the sloping platforms of Tasman Island and the adjacent dolerite coastline may have occurred as follows. When sea level rose to the present level, the rate of weathering in the joints of dolerite columns near mean higher high water increased over that maintained in the zones at higher elevations. As the joint planes became more weathered, waves were able to strip blocks down to a sloping surface which was dictated by pronounced oblique master jointing. Even though waves are powerful in this area, they can not quickly strip the material down to the next set of joints because adhesion at lower levels has not been sufficiently reduced by weathering. In addition, the vertical submarine cliff causes the portions of the waves below the sloping platform surface to reflect with little loss of energy.

The future of the sloping dolerite platforms of Tasman Peninsula will be one of gradually increasing width at the expense of the higher sub-aerial slopes. Submarine erosion will occur on the platform's seaward edge, through the agencies of biological action and occasional quarrying, but sub-aerial erosion will be taking place more rapidly at the higher elevations, widening the platform with the aid of wave stripping.

Chapter 9

SOUTH CROPPIES POINT PLATFORMS

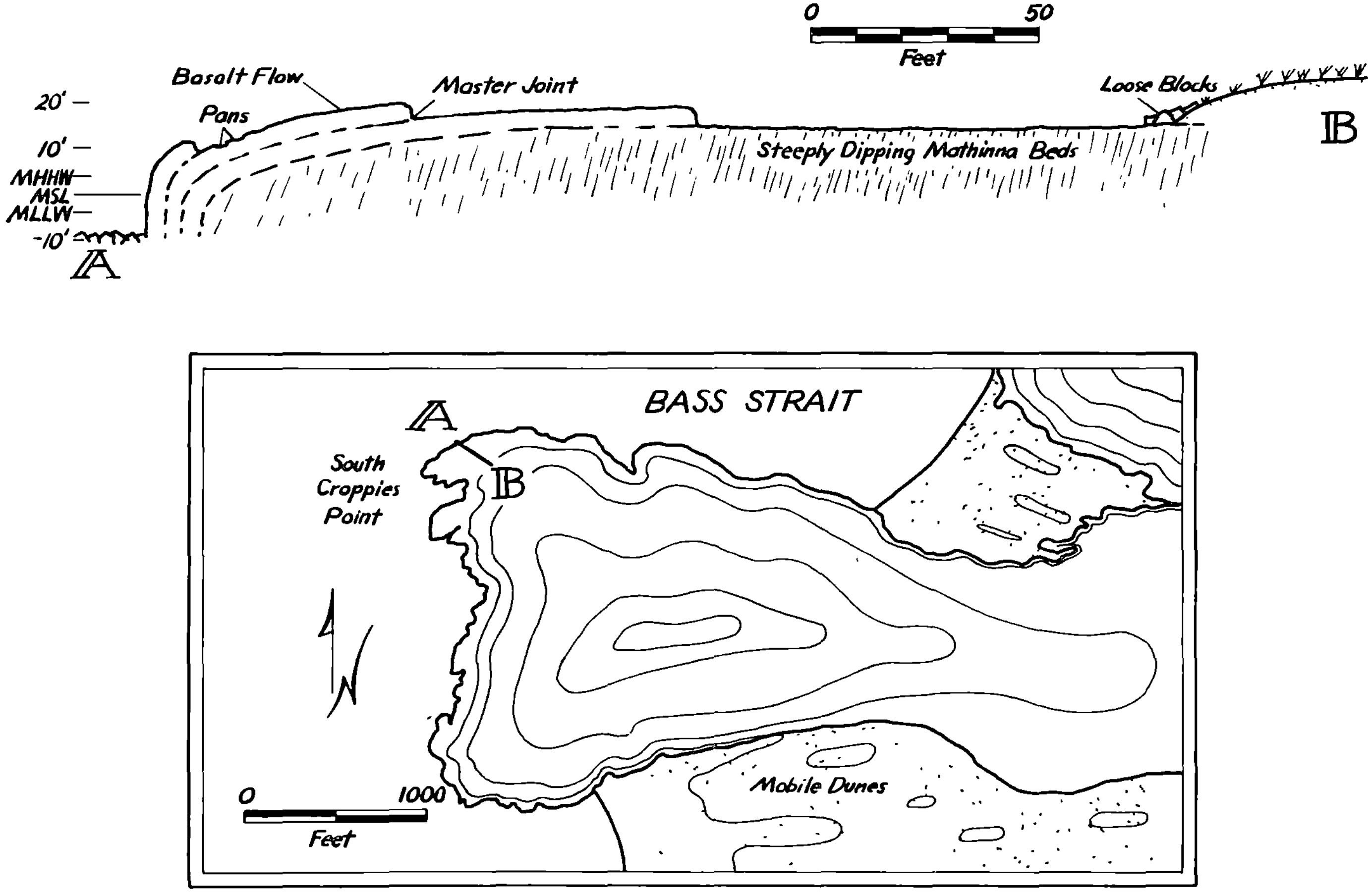
Platforms sloping along joint planes are fairly common in the doleritic rocks of Tasmania, as exemplified by the Tasman Island features. A sloping platform in basalt, however, is uncommon enough to deserve mention. South Croppies Point, on Bass Straight 25 miles northeast of Weymouth, is made up of a sloping basalt feature backed by an elevated, more horizontal structure carved in metamorphosed sediments.

STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

The basalt was extruded in the Tertiary period, possibly at the same time as the Weymouth rocks mentioned in Chapter 7. As in the case of Weymouth, the total basalt occurrence is relatively thin, having an exposed vertical dimension of only about 15 feet. Unlike Weymouth, however, the basalt has poorly developed vertical jointing and few horizontal planes of weakness except for pronounced, curved master sheet joints. The master sheet joints are horizontal about 120 feet inland from the edge of the platform, but change their dip to almost vertical at the seaward edge. The structure suggests that the basalt flow in this area responded to some irregularity in the underlying bedrock surface, resulting in master joints parallel to a curved contact zone. Bedrock consists of steeply dipping Mathinna Beds of Siluro-Devonian age which have

Figure 13

SOUTH CROPPIES POINT SKETCH PROFILE



0
50
Feet
Basalt Flow
Master Joint
Loose Blocks
20'
Pans
10'
MHHW
MSL
MLLW
-10'
Steeply Dipping Mathinna Beds
A
B
BASS STRAIT
A
South
Croppies
Point
B
N
Mobile Dunes
0
1000
Feet

been so altered by contact metamorphism that the original sedimentary characteristics are sometimes difficult to identify.

Sub-aerial topography is apparently strongly influenced by the presence of basalt flows in this region. Where the basalt has overlain the older rocks, headlands such as South Croppies Point occur. In between the headlands are lower areas now covered with mobile dunes. South Croppies Point itself is capped by a vegetation stabilized dune some 50 feet high. The Mathinna Bed surface emerges from under this cover at about fifteen feet above mean higher high water, approximately 225 feet southeastward from the seaward edge of the platform. An irregular, fairly horizontal zone, bevelling the steeply dipping Mathinna Beds, then extends for about 105 feet to the northwest. Here the Mathinna Beds are covered by a flow of basalt five feet thick which has a scarp on the southwestern end (Photo 24). Seaward from this point the platform profile becomes steeper, with uniformity interrupted by the cuesta-like edges of basalt flows. On the seaward edge of the platform the slope is almost vertical at the approximate level of mean higher high water.

From the seaward edge of the platform, the profile drops vertically to a depth of about -10 feet msl. The bottom at this point becomes nearly horizontal and is covered with basalt boulders which support lush biotic growth. Algae are well represented, but the bull kelp, Durvillea, is again absent, probably due to the warmth of the water. The offshore profile descends from the boulder zone onto a sandy bottom which reaches a depth of 60 feet, 2000 feet offshore.

CLIMATE

The climate at South Croppies Point is very similar to the climate at Weymouth, with moderate temperatures, about 25 inches of precipitation annually, summer sea breezes and northerly gales.

WAVE CHARACTERISTICS

Wave characteristics at South Croppies Point are slightly different from conditions at Weymouth. The northwest-facing point is exposed to higher wave energy, with the maximum wave heights probably reaching about 8 feet at least once every 5 years and about 12 feet every 100 years.

TIDAL REGIME

Tidal information is given in the Admiralty Tide Tables for Waterhouse Island, 4 miles northeast of South Croppies Point. The tables do not include harmonic constants, but range is given as 7.0 feet between mean high water springs and mean low water springs. As an estimate, the range between mean higher high water and mean lower low water is probably about 7.5 feet. The nearest station for which harmonics are listed is Georgetown, 40 miles to the west. Tides at Georgetown are semidiurnal in form, on the borderline with mixed, predominantly semidiurnal. The form at South Croppies Point should be much the same.

THE PLATFORM

The rounded profile of the seaward edge of the South Croppies Point platform is distinctly different from the sharp breaks in slope and extreme horizontality of other Bass Strait basalt platforms (Photo 25). The reason for this may be the variations in jointing characteristics of the different basalts. The Don Heads rocks have pronounced master sheet joints, well defined intermediate horizontal jointing, and good vertical columnar jointing. The only obvious joints in the South Croppies Point basalts, however, are the curving master sheet joints. A few irregular joints normal to the master sheet joints occur, but they are so few that the rock often appears massive. As was the case with Tasman Island, it is probable that weathering alone is not sufficiently effective to bevel the surface from its original slope without excavation by wave stripping to a level near mean higher high water. Such stripping would aid horizontal platform development both by directly removing material and by providing an extensive rock surface in the zone where most rapid weathering takes place due to optimum wetting and drying conditions.

Weathering appears to be active on the South Croppies Point platform. The sloping platform surface is profusely pitted

Photograph 24

South Croppies Point Platform. Mathinna Beds extend under the slope in the foreground. Basalt overlies Mathinna Beds in the seaward portion of the photo.

Photograph 25

Seaward edge of South Croppies Point Platform. Dipping basalt flows plunge beneath the sea.

between mean higher high water and about +10 feet msl and many pans are present. These may be as large as five feet in diameter and extend six to eight inches below the surrounding rock surface. Many pan edges show a notch form with a definite overhang. The floors of the pans are generally irregular, which may suggest that they have not yet reached saturation level. Because the pans are as much as six feet above mean higher high water, this may be the case. Conditions favor salt crystallization, as deposits of salt up to an inch thick lie in many depressions on the dark, heat absorbing surface.

Formation of Platform.

First step in the formation of the present South Croppies Point platform, when sea level neared its present elevation, was probably the stripping of soil and vegetation by wave action. Wave action then quarried blocks from the surface, as indicated by the large, angular boulders at the rear of the Mathinna Bed platform. This may have come about as weathering worked to weaken material in the few joints and rare, powerful northerly storms generated the large waves needed to shift the blocks. Basalt originally on the present Mathinna Bed platform may have been better jointed and less resistant to quarrying than the basalt further seaward, allowing stripping to the contact surface. With few horizontal planes of weakness in the seaward basalts, wave action merely stripped to the curved master joints, leaving weathering with the almost impossible task of reducing the surface to mean higher high water level.

The South Croppies Point platform will retain its present shape for a long time into the future. Wave action will continue to quarry an occasional block from the rounded seaward edge of the platform and biological action will take its toll, but weathering will have difficulty in establishing a large area of horizontality.

Chapter 10

GRANT POINT PLATFORMS

A large portion of the northeastern coast of Tasmania consists of granitic rocks which may support sloping shore platforms above the level of mean higher high water. Grant Point, 10 miles northeast of St. Helens and 120 miles northeast of Hobart, has a "granitic" shoreline which typifies the morphology of that rock type.

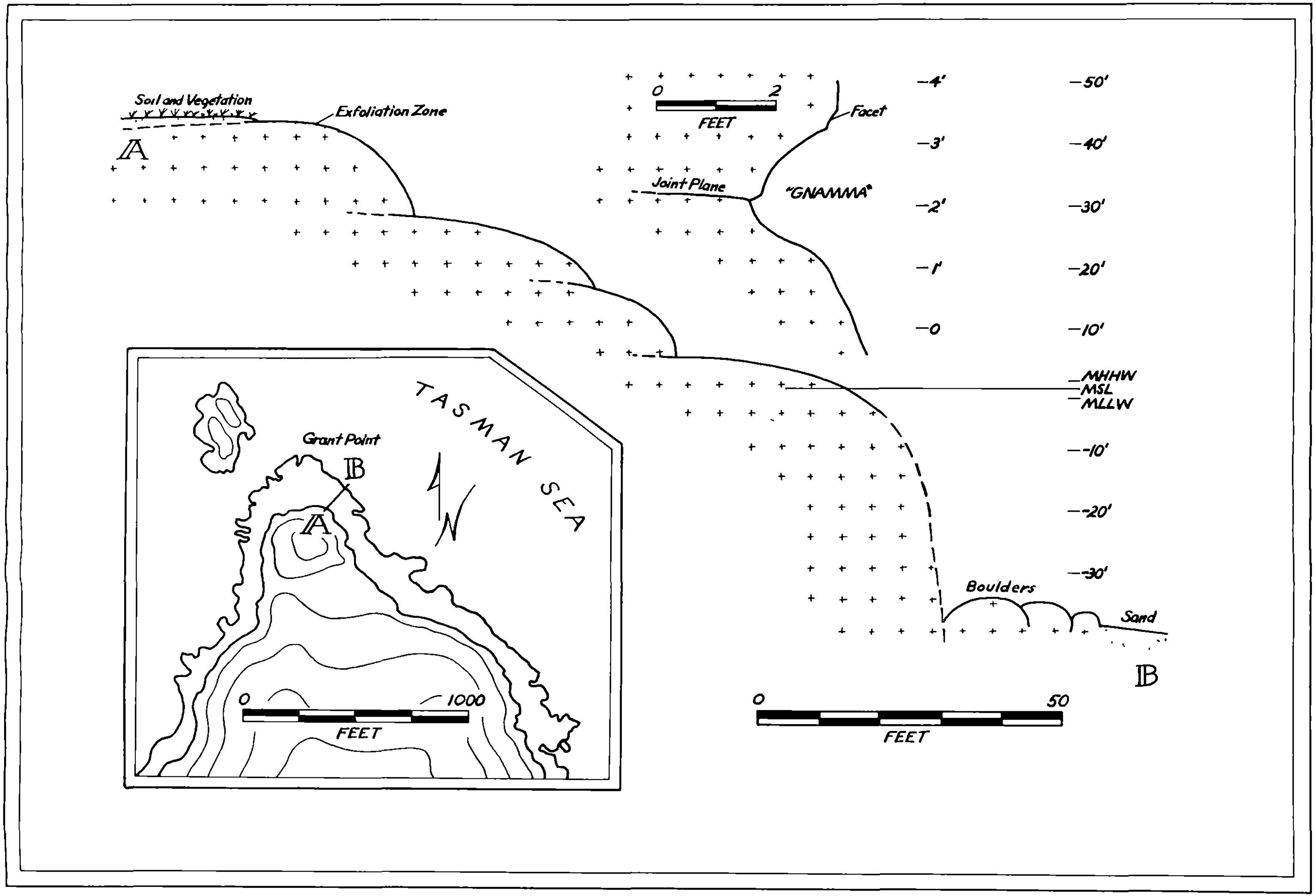
STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

The grey granodiorite of the region is of probable upper Devonian age, and intrudes into Devonian and Silurian Mathinna Beds which have been subsequently removed by erosion. The coast of Grant Point, in common with the rest of the "granitic" northeast, consists of rounded, massive forms, separated by curved master joints. The prominent coarse jointing is probably related to cooling isotherms in the solidifying rock. Because isotherms are roughly parallel to the intrusive surface, horizontal joint patterns are rare in this locality of domed intrusions.

Grant Point granodiorite is coarse grained and holocrystalline without prominent internal structure. Examination of a thin section shows that the rock is composed predominantly of quartz and feldspar, with some ferromagnesian minerals. The ferromagnesians

Figure 14

GRANT POINT SKETCH PROFILE


Soil and Vegetation
Exfoliation Zone
A
0 2
FEET
Facet
Joint Plane
"GNAMMA"
-4'
-3'
-2'
-1'
-0
-50'
-40'
-30'
-20'
-10'
MHHW
MSL
MLLW
-10'
-20'
-30'
Boulders
Sand
B
0 50
FEET
TASMAN SEA
Grant Point
B
A
0 1000
FEET

crystallized first, followed by the feldspars and finally, quartz. Consequently, quartz forms a "cement" around the other minerals and the porosity of the rock is low.

CLIMATE

Grant Point is located in an environment which would appear favorable for weathering. Temperatures are warm, with a January mean of about 60^{o} and an extreme highest temperature of slightly over 100^{o}F. July mean temperature is 46^{o} and the extreme lowest temperature was about 20^{o}F. Annual precipitation is about 35 inches. Incidence of cloud is fairly low, compared with other portions of Tasmania, and the abundance of sunlight combines with considerable wind flow to produce an evaporation rate which should be at least as great as the 31 inches reported at a station 60 miles to the south. An afternoon sea breeze commonly blows from the east on summer afternoons, reaching strengths of about 20 knots. Infrequently, southeasterly to northeasterly gales strike the area.

WAVE CHARACTERISTICS

Waves striking Grant Point vary from a long low swell, through chop raised by the sea breeze, to waves which may reach heights of 15 feet or more during cyclonic conditions in the Tasman Sea. Wave activity is certainly ample to keep the platform free of debris due to weathering or other causes.

TIDAL REGIME

Tidal regime is far less than that encountered on the Bass Strait coast. The range between mean higher high water and mean lower low water is only 3.3 feet at Eddystone Point, 20 miles to the north, and is probably much the same for Grant Point. With $\frac{K_1 + O_1}{M_2 + S_2} = 0.56$, tides are mixed, predominantly semidiurnal.

THE PLATFORMS

The shore platforms of Grant Point show the influence of a bedrock type which has widely spaced, curved joints; is non-porous; and which has quartz "cement" around other constituent minerals. The platforms are merely the tops of rounded forms outlined by the curving joint planes and have no consistant altitude relationship to mean higher high water. In spite of favorable environmental conditions, weathering is slow, possibly because of the quartz "cement" around the individual mineral grains. The low porosity may be another factor, limiting wetting and drying phenomena to a very thin surface layer. The weathering which does take place receives little help from wave quarrying in the attempt to produce a horizontal surface near high tide. Wave stripping of material to the widely spaced jointing planes often leaves a great amount of massive rock which weathering must displace before an equilibrium level can be reached.

The northeastern tip of Grant Point, exposed to the Tasman Sea, has a profile which is duplicated qualitatively on much of the "granitic" coastline of northeastern Tasmania. The bedrock emerges from a cover of soil and vegetation at an elevation of about 40 feet. Large spherical slabs of rock are exfoliating in this zone, which is kept free of debris and soil by occasional heavy spray from storm waves. From the 40 foot level, the profile drops in a series of convex upwards curves to about -35 feet over a horizontal distance of 110 feet. A shore platform about 30 feet wide extends from +5 feet msl to about -2 feet msl where it grades evenly into an almost vertical slope. Rough water prevented examination of the submarine portion of the profile, but investigation in sheltered water around the tip of the point suggests that large boulders lie at the foot of the submarine slope, with sand occurring seaward at a depth of about 40 feet.

Some of the surface of the "high tidal" platform is covered with quite large boulders, but much of it is bare rock which shows occasional signs of water-layer weathering. A few flat pans are present, with incipient overhanging rims, and some of the jointed blocks and boulders are undercut at the platform surface. Biochemical reactions may be taking place on the platform, as it is covered with algae, barnacles and littorinids.

"Gnammas"

Weathering also causes notches higher up on the profile, at the interfaces between the large joint blocks (Photo 27). Structures sometimes occur which are similar to the "gnammas" described in arid regions of Australia by Twidale and Corbin (1963). The basic shape of the "gnamma", a rounded pit in granite, is similar, but the orientation is not. Twidale and Corbin's "gnammas" had a vertical or inclined main axis, while the Grant Point features have the main axis on a horizontal plane. Grant Point "gnammas" are roughly parabolic in shape and are about 1.5 feet deep and 2.0 feet high. Although surfaces are for the most part smoothly concave, faceting may take place on the more exposed areas. The lower block is often more deeply eroded than the upper block, leaving a protrusion above the joint plane. Twidale and Corbin mentioned a number of factors in the formation of the "gnammas", among them etching by lichen, kaolinization, salt crystallization, hydration and flaking of laminae. Any or all of these processes could conceivably be operating on the Grant Point features, but salt crystallization and hydration are probably the most important.

Formation of Platform.

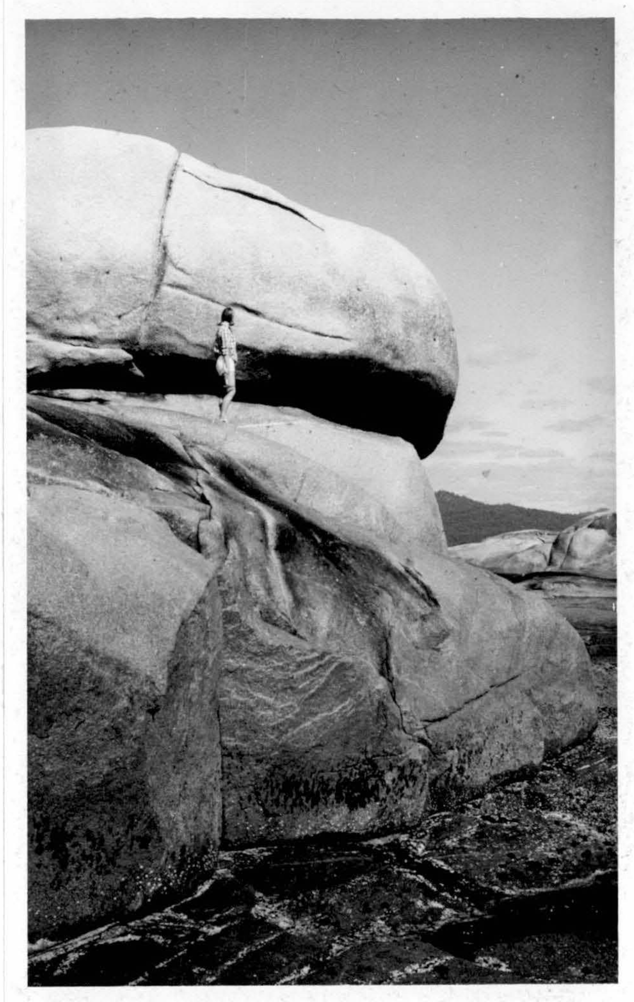
Unlike most of the other platforms included in this study, the Grant Point feature shows little dependence on proximity to present sea level for its morphology. When sea level rose to its present height, a surface already existed which was near high tide level. This surface was probably the result of sub-aerial exfoliation and

Photograph 26

Grant Point. A "Gnamma" has been formed adjacent to the joint at an elevation of about 30 feet, msl.

Photograph 27

"Gnamma" at Grant Point. The photo is a close-up of the "Gnamma" shown in Figure 26.



weathering to a curved joint plane. If the platform had not been present, with sea level rising to a point midway between two widely spaced joints, the plunging cliff often found on granitic shorelines would result.

Although the Grant Point platform was not formed in conjunction with present sea level, marine forces are now modifying even this recalcitrant rock. Given enough time, the combined efforts of mechanical and chemical weathering could overcome the disadvantages of coarse, curved jointing, lack of porosity and resistant minerals in the production of a level platform at the elevation of mean higher high water.

Chapter 11

ST. HELENS PLATFORMS

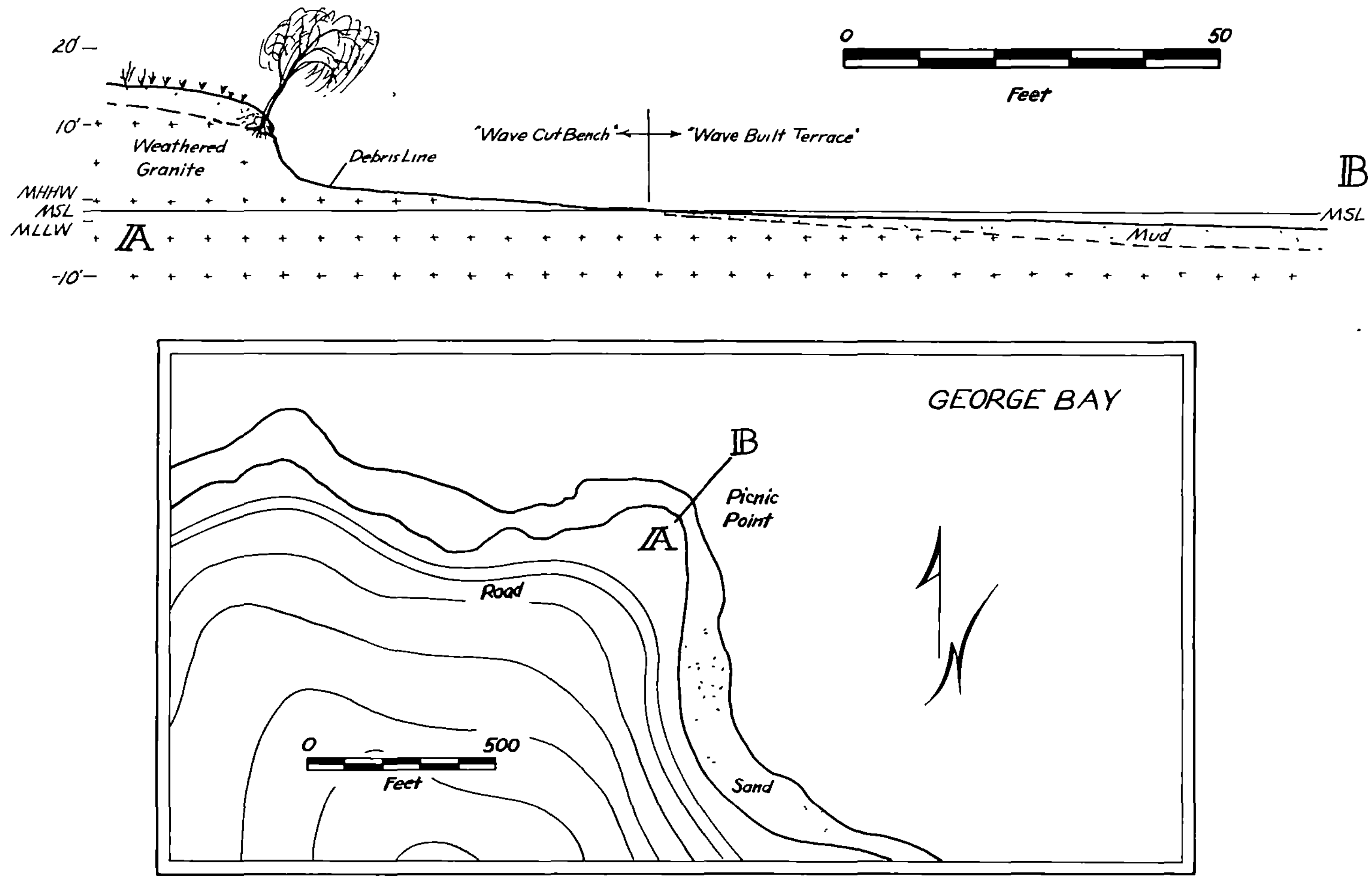
Not all of the Tasmanian platforms have surfaces near or above mean higher high water. Some platforms, the intertidal features, extend from mean higher high water to mean lower low water with profiles often similar to the classic "wave cut bench" diagrams common in textbooks. In addition to the concave profiles, the Tasmanian coastline exhibits intertidal and transgressive platforms with convex morphologies. The concave surfaces are usually due to actual marine erosion of the bedrock, while the convex profiles result from marine exhumation of a bedrock surface which has been previously shaped by sub-aerial weathering. An example of an intertidal platform with a concave profile occurs in the sheltered waters of Georges Bay, about 1/2 mile southeast of the town of St. Helens.

STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

Mineralogically, the rock type is similar to the granodiorites of Grant Point, 10 miles to the northeast, and was probably intruded at the same time in the upper Devonian. However, where the Grant Point rock is still strong, the St. Helens granodiorite is deeply weathered and quite friable. The difference may be due to the burial, noted by Walker (1957) of the

Figure 15

ST. HELENS PROFILE



20'
10'
MHHW
MSL
MLLW
-10'
Weathered Granite
Debris Line
"Wave Cut Bench"
"Wave Built Terrace"
0
50
Feet
A
B
MSL
Mud
GEORGE BAY
B
A
Picnic Point
Road
Sand
0
500
Feet

St. Helens rock by Tertiary gravels which have since been largely removed. Ground water may have saturated the underlying granodiorite and caused weathering to a considerable depth. The Grant Point granodiorite might have avoided a similar fate because of freedom from gravel cover. Deposits could have thinned out before reaching the Grant Point vicinity as the source area for the gravels was in the west.

The deeply weathered nature of the St. Helens granodiorites appears to exert major influence over the platform morphology. Platforms are intertidal, with gentle concave slopes which become increasingly steep landward of the high tide mark. The general pattern of the profile is similar to those developed in unconsolidated sediments and strongly suggests simple wave removal of the weathered granite material.

CLIMATE

The climate at St. Helens is influenced less by maritime conditions than the climate at nearby Grant Point. Summer temperatures are higher, with a January mean of about 62^{o}. Winter temperatures also differ, having a July mean of approximately 45^{o}. Precipitation, however, is much the same as at Grant Point; about 35 inches per year falls at both locations. Winds are also similar, with summer afternoon sea breezes and occasional southeasterly to northeasterly gales.

WAVE CHARACTERISTICS

Even though the platforms are protected from the open ocean, Georges Bay is big enough to allow the generation of waves capable of active erosion. The fetch across Georges Bay from the platform location is about 3 miles in a north-eastern direction. Bretschneider's (1952) tables show a significant wave height of four feet for a 3 mile fetch and a 40 knot gale; a condition probably attained at least once a year. Similarly, a 20 knot sea breeze could produce waves about two feet high almost every day during the summer. The generated waves are presently undermining the sea cliff and moving the eroded material into storage on pocket beaches flanking the headlands.

TIDAL REGIME

The closest location for which detailed information is available is Eddystone Point, 25 miles to the north on the open coast. The range between mean higher high water and mean lower low water at Eddystone Point is 3.3 feet and tides are mixed, predominantly semidiurnal. The Tasmanian Public Works Department operated a tide gauge at St. Helens for a brief period which showed roughly similar values.

Photograph 28

St. Helens Platform. The geology pick is embedded in weathered granite.

THE PLATFORM

The platform on Picnic Point is typical of the weathered granodiorite forms on the shores of Georges Bay and was selected for levelling with the theodolite (Photo 28). Picnic Point has a level surface at about 15 feet msl which may be part of an ancient terrace and is now used as a picnic ground. At the seaward edge of the 15 foot surface the slope gradually increases until reaching about 70°, 6 feet above mean sea level. Many tree roots are uncovered on the steep portion of the cliff, intertwining in an organic mat which is undercut in places. Weathered granodiorite is exposed immediately below the break in slope, dropping at an angle of 45°. The slope changes from 45° to about 4° within a horizontal distance of 7 feet and then decreases gradually further seaward.

A line of seaweed and other debris at the 4° point indicates that the normal sea breeze waves probably do not reach the base of the cliff, and suggests that storm waves are the agent of erosion in that zone. The debris line is about 1.5 feet vertically above the approximate level of mean higher high water and about 3.0 feet above sea level. This location of the line would be compatible with sea breeze generated waves and the normal range of high tides. The lack of horizontality in this zone immediately above high tide could be due to the extremely weathered nature of the rock, which allows the waves to winnow away the grains regardless of any level of saturation. In addition, the bedrock is so porous that the saturation level may move considerably with the tides.

In the vicinity of the debris line a thin veneer of coarse quartz gravel lies over the weathered bedrock. Seaward, the gravel is replaced by a few pebbles, but the cover is not heavy. The bedrock surface becomes completely buried by mud 50 feet from the sea cliff and this covering continues seaward for another 100 feet at a slope of 2°. The seaward limit of the mud surface is marked by a rapid slope increase and a channel about 40 feet deep.

The profile suggests that the portion of the platform seaward of the debris line has reached an almost stable configuration, while the landward section is being more actively cut by the action of storm waves. On the part of the platform extending seaward, deposition is producing a form which might be analogous to the textbook "wave built terrace". However, this terrace contains none of the coarse quartz gravel of the eroding sea cliff and is instead composed of very fine grained material, probably brought in laterally by currents.

Future Development of Platform.

If sea level remains constant, the present intertidal platform will progress landward at the expense of the elevated portiom of "Picnic Point". Storm waves will continue to erode the base of the cliff, causing the slumping of the soil and organic material above. The more horizontal area seaward will gradually become lower as the cliff retreats, until a level is reached where wave action is no longer able to either erode the bedrock or keep the mud from settling on the surface. It is likely that the width of the rock platform will remain constant as the profile moves landward, with cliff retreat matched by mud encroachment. The mud surface will gradually widen, with its seaward edge next to the channel fixed in position by the underlying bedrock. In this manner the morphology of "wave cut bench" and "wave built terrace" will continue to exist at Picnic Point, St. Helens as one of the few Tasmanian examples of the classic coastal profile.

Chapter 12

APEX POINT PLATFORM

Apex Point, on the western side of Tasman Peninsula, supports a sloping shore platform which is quite different from the St. Helens feature. The Apex Point platform has a convex profile which extends from about 10 feet above mean higher high water to approximately 20 feet below mean lower low water, transgressing all the elevational zones from supratidal to subtidal. This profile type is not limited to the Apex Point dolerite, however, as it occurs elsewhere in Tasmania where resistance of rocks to rapid weathering or unfavorable structure discourages horizontal shore platform development. In these cases the profile represents the rock surface which remains when wave action removes the overlying soil cover (Photo 29).

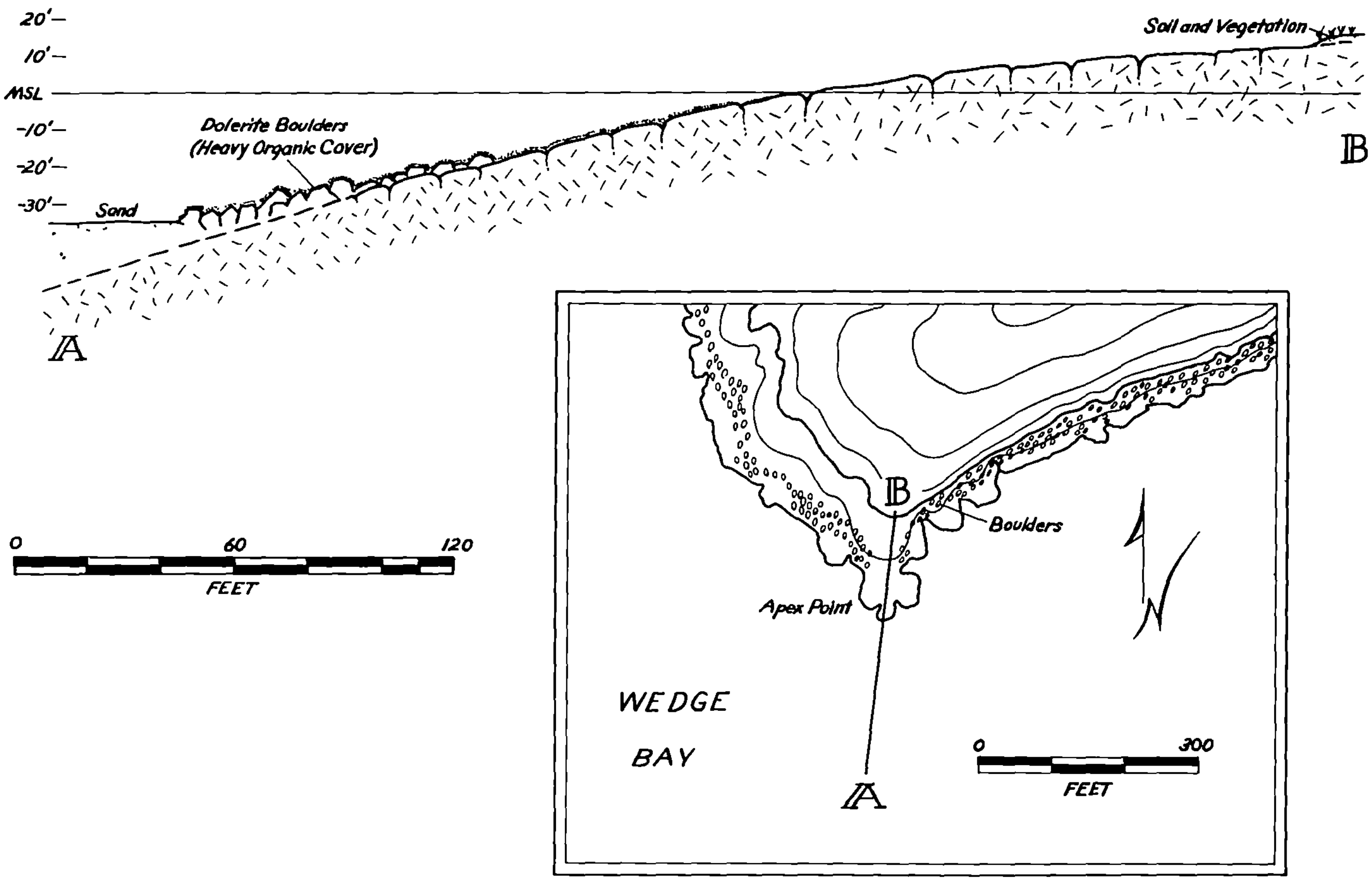
STRUCTURE AND GEOMORPHOLOGICAL CONTEXT

Rock type in this area, 25 miles southeast of Hobart, is Jurassic dolerite. The dolerite is far less weathered than the friable St. Helens granodiorite; probably an important factor in the differing profile development of the two platforms.

Apex Point dolerite is jointed both horizontally and vertically. The curving, sub-horizontal sheet joints are very prominent and exert a strong control over the local morphology.

Figure 16

APEX POINT SKETCH PROFILE



20'
10'
MSL
-10'
-20'
-30'
Sand
Dolerite Boulders
(Heavy Organic Cover)
Soil and Vegetation
B
A
0
60
120
FEET
B
Boulders
Apex Point
WEDGE
BAY
N
A
0
300
FEET

In contrast, vertical jointing is poorly developed, with little of the regularity exhibited in the Tasman Island dolerite further to the south.

Apex Point is the western end of an east-west trending, narrow ridge which slopes from a height of 276 feet to sea level over a distance of 3400 feet. The ridge extends into Wedge Bay and is flanked by the entrance to Parsons Bay on the north and an indentation which joins White Beach on the south. Soil cover on the ridge is thin and supports grass, bracken and a few trees. Dolerite boulders commonly occur on the portions of the ridge now subject to wave action, with major concentrations stored in small embayments. The points, such as Apex Point, are relatively free of boulder cover above -15 feet msl.

CLIMATE

The climate at Apex Point includes an average annual precipitation of 30 inches, mean January temperature of 58°F. and mean July temperature of 47°F. The temperature has never dropped below 25°F. and the extreme highest temperature recorded was 97°F. Evaporation for the year is between 31 and 34 inches, with the maximum in the summer months. These conditions are quite similar to much of southeastern Tasmania, including Eaglehawk Neck and Kangaroo Bluff. Winds include several northwesterly to southwesterly gales every year in addition to almost daily southerly afternoon sea breezes in the summer.

WAVE CHARACTERISTICS

The westerly gales blow directly onto Apex Point across a fetch of about 15 miles and generate the highest waves which affect the area. These waves when combined with swell probably have a significant height of about 8 feet. Apex Point is sheltered from waves caused by the sea breeze, so that the most prevalent wave form is a low, refracted southwesterly swell. Protection from the full effect of the southwesterly swell is afforded by Wedge Island just offshore and Bruny Island across Storm Bay.

TIDAL REGIME

Tides are mixed, predominantly diurnal, with $\frac{K_1 + O_1}{M_2 + S_2} = 1.63$. Two high waters generally occur daily with marked inequalities in height and phase. After maximum declination of the moon, only one high water takes place in a 24 hour period. Mean range between mean higher high water and mean lower low water is 2.7 feet, based on data included in the <u>Admiralty Tide Tables</u>.

THE PLATFORM

The platform at Apex Point extends along the shore for a distance of 100 feet and is at least 220 feet long from upper to lower edges. Lateral limits are established by small re-entrants in the coastline which apparently result from erosion of jointed material. The upper margin of the platform is 135 feet from the mean sea level line at an elevation of 12 feet msl. At this point the rock surface is covered by a layer of soil about one foot thick (Photo 30). The lower limit of the platform is more difficult to define. The surface extends uniformly seaward from the mean sea level line for about 85 feet, where it reaches a depth of 16 feet. The rock is matted with thick, continuous biotic growth on the underwater portions. At a depth of 16 feet, the platform becomes blanketed with a veneer of loose dolerite blocks. Some of the blocks are 4 or 5 feet in diameter and the collection completely buries the platform surface, which probably continues underneath. Thick growth on the blocks indicates that they are very rarely disturbed by wave action. The blocks form a continuous cover to a depth of 35 feet, 175 feet from the mean sea level line. Here the continuity is broken by patches of sand mixed with shells. The sand-shell surface becomes more prevalent seaward, as the density of boulder cover decreases.

Formation of Platform.

In contrast to many of the examples mentioned in preceding pages, the sea had little to do with the formation of the Apex Point platform. The actual profile in this instance was probably established by the rock structure, with additional

Photograph 29

Apex Point Platform. The exposed rock platform continues the sub-aerial profile of the descending soil-mantled surface.

Photograph 30

Landward Edge of Apex Point Platform. Wave action has uncovered the bedrock surface seaward of this point.

trimming by sub-aerial weathering processes. The present platform surface may represent a previous basal plane of weathering. Pitting and flaking on the surface which extends beneath the soil cover suggests that this may be the case. When the sea came in contact with the soil-covered surface, waves removed the unconsolidated material and exhumed the present platform. The upper limit of the platform is the zone where the erosive force of the waves is just balanced by the ability of a tangled mat of roots to hold the soil in position.

The present platform surface is not absolutely uniform. Some blocks have been quarried from the higher elevations and deposited offshore. In addition, the continuity of slope is broken by a slight concavity at about the level of mean higher high water. This may be merely a structural feature or it could be an indication of bevelling activity. To the extent of some quarrying and possible bevelling, the sea may be altering the surface, but the overall profile remains a sub-aerial form.

Many other examples of this profile exist on the Tasmanian coast. In general the transgressive profile occurs when well consolidated rocks resistant to weathering come in contact with the sea. If rocks are not well consolidated, the concave St. Helens profile results, while bevelled platforms like those at Eaglehawk Neck occur if the rock weathers rapidly. The

Cambrian and pre-Cambrian quartzites and schists of the Tasmanian north and west coasts which are indurated and weather poorly often show the exhumed surface of the transgressive profile. In addition, dolerite and granite coasts may exhibit this profile type.

Future Development of Platform.

The future development of the Apex Point platform depends on the stability of sea level. A rise in level would extend the upper limit of the platform by stripping back the soil cover. Conversely, a drop in sea level would allow the upper part of the platform to accumulate a soil and vegetation mantle. Boulders presently in storage below -15 feet msl might be moved into the flanking embayments if sea level were lower, resulting in a downward shift of the exposed portion of the platform.

If sea level remains constant, the Apex Point platform will undergo very slow alteration. Wave quarrying will occasionally remove a block from the platform and weathering may in time produce a limited horizontal surface near the level of mean higher high water. These activities will operate much less rapidly at Apex Point than in rocks with more favorable structure and weathering properties such as the Permian sandstones of Eaglehawk Neck.